SSS-SR-04-01
NASA8-35042

(NASA-CR-170737) DEFINITION OF TECHNOLOGY DEVELOPMENT MISSIONS FOR EARLY SPACE STATION SATELLITE SERVICING, VOLUME 2 Final Report (Martin Marietta Aerospace) 188 p HC A09/MF A01 CSCL 22A G3/12

N83-26851

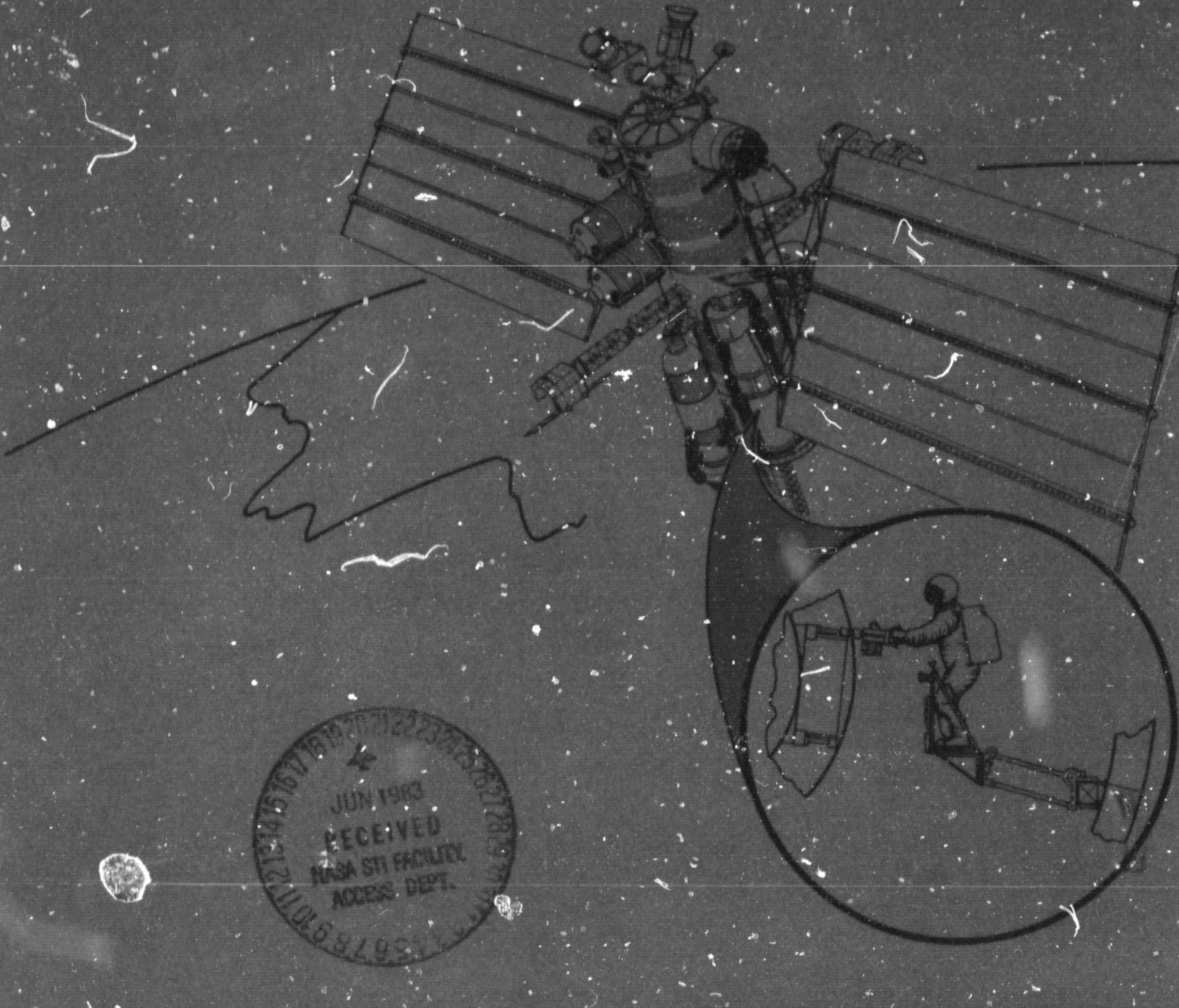
Unclas
03900

Volume II

Final Report

May 1983

Definition of Technology Development Missions for Early Space Station Satellite Servicing



MARTIN MARIETTA

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Volume II	Final Report	May 1983

DEFINITION OF TECHNOLOGY DEVELOPMENT MISSIONS FOR EARLY SPACE STATION SATELLITE SERVICING

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FOREWORD

This final report, submitted to National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC), presents the results of the Definition of Technology Development Missions for Early Space Station-Satellite Servicing performed by the Space and Electronics Systems Division of the Martin Marietta Corporation under NASA Contract NAS8-35042.

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1.0 INTRODUCTION AND SUMMARY

1.1 PURPOSE

The purpose of this study was to establish the feasibility and requirements for demonstrating a satellite servicing capability on a permanent manned space station in the early 1990s. The primary study objectives were: 1) Define the test bed role of an early manned space station in the context of a satellite servicing evolutionary development and flight demonstration technology plan resulting in an operational satellite servicing capability in the late 1990s; and, 2) Conceptually define a satellite servicing technology development mission (or set of missions) to be performed on an early, evolving space station to demonstrate the capability to routinely perform satellite servicing activities.

1.2 SCOPE

This study established early space station satellite servicing requirements, mission definition, accommodation needs and the associated programmatic schedules and costs. These analyses were developed for the three basic satellite servicing concepts of: 1) Modification of the space station itself during its evolution; 2) repair and/or upgrading of satellites; and, 3) assembly of space craft whose volume/configuration exceeds the STS payload capability of an individual flight.

The study results are presented in two volumes: Volume I, Executive Summary; and, this volume - Volume II, Final Report.

Volume I, Executive Summary, summarizes the specific results, achievements and activities of the study.

Volume II, Final Report, presents the results of all aspects of the early space station satellite servicing study tasks. These results include identification of servicing tasks (and locations), identification of servicing mission system and detailed objectives, functional/operational requirements analyses of multiple servicing scenarios, assessment of critical servicing technology capabilities and development of an evolutionary capability plan, design and validation of selected servicing Technology Development Missions (TDMs), identification of space station satellite servicing accommodation needs, and the cost and schedule implications of acquiring both required technology capability development and conducting the selected TDMs. This document presents the study analyses data and results of this study phase, and provides a detailed expansion of the summary results presented in Volume I, Executive Summary.

Appendix A, Acronyms and Abbreviations, presents a reference list of those common to both volumes of the study.

Appendix B, Reference Bibliography, presents a listing of all primary references used to develop the data used throughout the Satellite Servicing study.

1.3 APPROACH

The results of this study were developed by performing the analyses as shown in the Satellite Servicing study flow, Figure 1.3-1. This study flow is consistent with the requirements of the contractual tasks identified in the statement-of-work. These three tasks are as follows:

1) Task 1-Mission Requirements - The purpose of this task was to identify satellite servicing and maintenance capabilities from which requirements and servicing objectives could be derived. The analyses emphasized by this task was the development of a satellite servicing data base, consisting of a time phased satellite servicing mission model, the development of potential servicing tasks and locations (servicing scenarios) and associated Mission/System/Detailed Objectives, the development of system and hardware accommodation requirements and the identification of technology capability needs and development.

2) Task 2 Mission Definition - The purpose of this task was to develop Technology Development Mission (TDMs), establish their operational requirements and accommodation needs that will satisfy the requirements and servicing tasks developed by Task 1. The analyses emphasized were: 1) the development of time phased TDMs that resulted in the demonstration of the capability to perform routine satellite servicing tasks from the early space station; 2) the evaluation of the operational concepts and approaches to identify operational requirements and hardware; and, 3) the evaluation of accommodation needs, special servicing equipment required on the space station to accommodate the satellite servicing capability and the identification of satellite, space station, and servicing hardware interfaces.

3) Task 3 Programmatic Analysis - The purpose of this task was to generate the plans, schedules, and costs for implementation of the TDMs. The analyses emphasized were space station capability evolution, satellite servicing economic benefits, precursor technology capability schedules, TDM performance schedules, and the associated TDM costs.

1.4 GROUND RULES AND GUIDELINES

The following ground rules and guidelines were used as the basis of analyses in the performance of this study.

1. Maximum utilization was made of applicable data and results from prior and current projects and government-sponsored studies.

2. The Space Shuttle was considered as the Earth launch vehicle and the Space Shuttle User's Handbook was used to provide the associated guidelines.

3. An early space station will be operational in 1990.

4. A Teleoperator Maneuvering System (TMS) will be available to support on-orbit operations.

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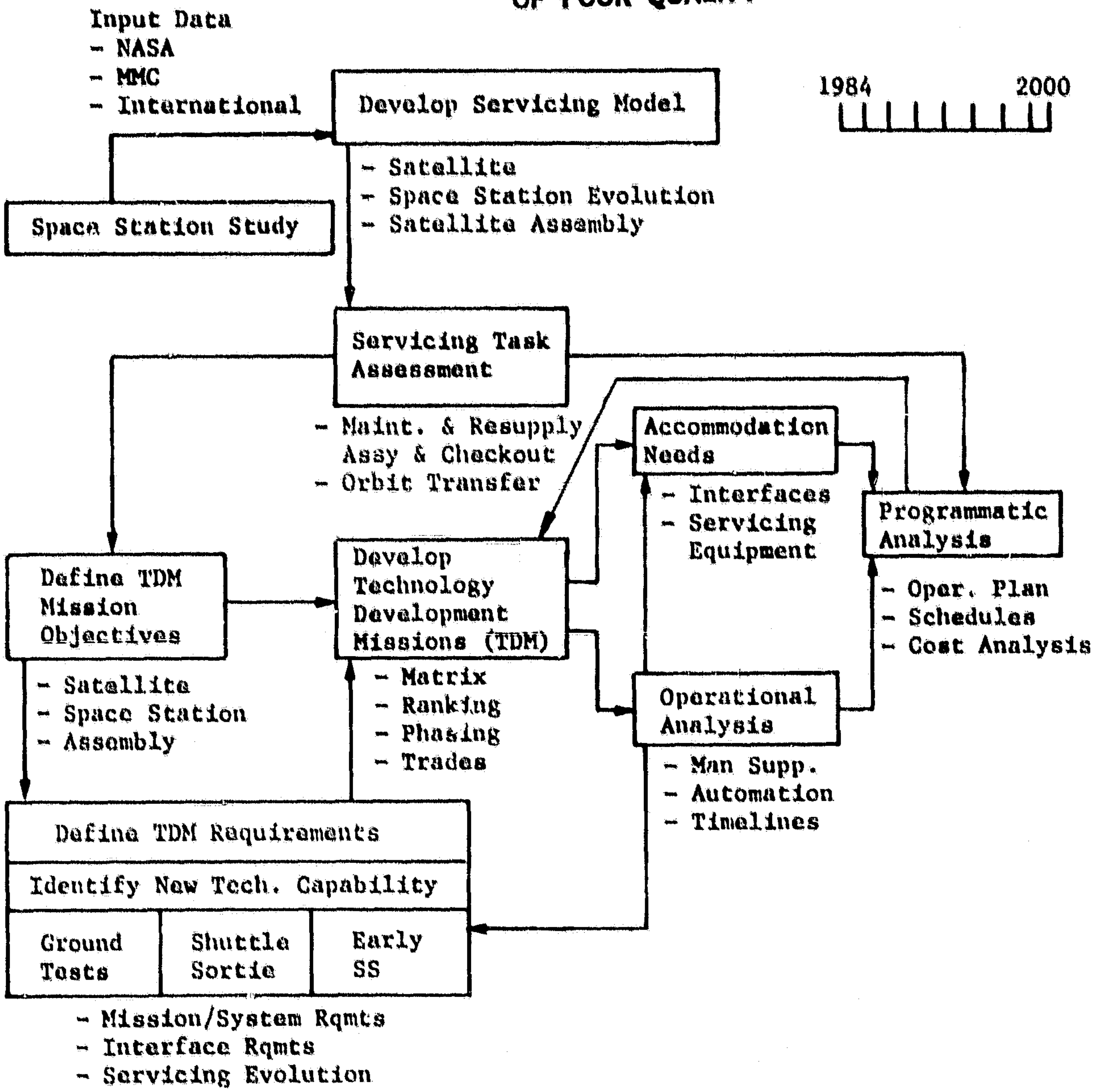

Figure 1.3-1 Satellite Servicing Mission Flow Diagram

1.5 SUMMARY

The overall objective of the Space Station Satellite Servicing study was to define the evolutionary development of a satellite servicing capability on a permanent manned space station in the early 1990s, and to conceptually design Technology Development Missions (TDMs) to demonstrate the satellite servicing capabilities on the early space station. This objective was met with the selection and validation of eight TDMs designed to satisfy the four derived servicing tasks of assembly, orbit transfer, resupply, and maintenance. Completion of these time phased TDMs will demonstrate a satellite servicing capability to perform the servicing tasks at or remote from the space station so that satellite servicing can become a routine activity from the early space station. Three tasks were accomplished during the course of this study to achieve the results necessary to accomplish the study objective, these tasks are; Task 1 - Mission Requirements, Task 2 - Mission Definition, and Task 3 - Programmatic Analysis. The summaries of these three tasks are as follows.

Task 1 Mission Requirements - The analyses included in this task are; a satellite servicing data base, servicing task and location (scenarios), evaluation of the servicing scenario requirements and the identification of objectives and capabilities needed to accomplish the servicing tasks. Mission model analysis revealed a broad range of servicing tasks. The Martin Marietta Space Station Satellite Servicing Mission Model identified 185 satellite systems existing and/or planned for operations during the decade of the 1990s, with 387 servicing tasks projected during the early space station period. Servicing task and location assessment (servicing scenarios) produced four major task areas that subdivide into 10 associated subtasks. These tasks and subtasks are:

1) Assembly - space station assembly and onorbit assembly of large spacecraft;

2) Orbit transfer - delivery and retrieval of spacecraft to and from operation orbits using the space station as a base of operations;

3) Resupply - resupply of fluids (earth storable and cryogens) and material (logistics, modules, raw materials, instruments);

4) Maintenance - Conduct of planned and unplanned repair operations and decontamination operations.

Servicing tasks will be conducted in three locations: 1) on the space station itself; 2) on satellites berthed at the space station; and 3) on satellites remote from the space station in low or high earth orbits.

Mission objectives were developed for each of the four major servicing tasks; assembly, orbit transfer, resupply, and maintenance. From the four top level mission objectives, 21 primary system level objectives and 230 detail level objectives were formulated.

Functional and operational analyses were developed for the servicing tasks and locations (mission scenarios). 112 satellite servicing scenarios were identified and through an iterative process of cross-checking and comparison these sequences were reduced into a total of 18 functional analyses that included the servicing activities required in performing servicing tasks at all potential servicing locations. These functional analyses resulted in identification of servicing requirements hardware/facilities and technology capabilities required to provide these operational servicing abilities in the early space station era. These requirements include structural and mechanical equipment and facilities, data processing and display, audio and visual communications, handling equipment (such at a Space Manipulator Arm/Space Crane, work stands, hangar extensions, etc), and servicing and storage facilities for transfer vehicles and servicers. The development of satellite servicing integrated requirements and their functional analysis for the TDMs was accomplished in parallel with this study but these efforts were funded through Independent Research and Development. These analyses also identified technology capabilities that would be required to perform the identified servicing tasks. As a result, a technology development survey was conducted to: (1) determine the status of key technologies required for servicing and (2) recommend additional technology development efforts if required. Seven key servicing technology areas were identified as required to support the satellite servicing task performance. These were:

a. Orbital Fluid Transfer;

b. Teleoperator Maneuvering System (TMS);

c. Orbital Transfer Vehicle;

d. Servicers (remote servicing operations);

e. Space Automation;

f. Onorbit Maintenance;

g. Servicing Operations/Control.

From the results of the technology survey, a comparison of required versus available or planned technology development enabled production of the Evolutionary Technology Plan (ETP). The ETP reflects the status of technology efforts either underway or planned for ground studies or experiments, Shuttle flight technology experimentation or demonstration, and planned space station technology. In addition, recommended technology studies, development and test demonstrations on STS and on the space station are included in the ETP to provide a plan which will ensure requisite technology is available for conduct of TDMs on the early space station. No new technologies were identified as required for satellite servicing that are not under development at the present time, and are planned or can be replanned to satisfy the time phased satellite servicing capability buildup on the early space station.

Task 2 Mission Definition - The analyses included in this task are the development of time phased TDMs, the associated operational analyses, and the development of the space station accommodation needs to provide the required satellite servicing capabilities.

A TDM is a mission designed to demonstrate a specific satellite servicing capability or set of capabilities. They were developed to provide for the demonstration of the time phased servicing capabilities of the space station and provide proof of concept for space station installed equipment and operational concepts. Mission level TDMs will be conducted either at the space station, remote from the space station, or a combination of both. Precursor TDMs are those missions or activities necessary to verify or validate independent system or subsystem elements required prior to the performance of a specific TDM. Candidate TDMs were selected and analyzed to evaluate the contribution of each to meeting established servicing needs. These TDMs were designed to utilize operating, in-being satellite systems to economically demonstrate satellite servicing operational capability at the early space station. From the candidate TDMs, it was determined that eight (8) mission TDMs would satisfy the servicing task requirements. TDMs satisfy the three satellite servicing concepts specified in the Statement of Work, which were:

a. Modification of the space station during its evolution;

b. Repair and/or upgrading (including delivery, retrieval, and resupply) of satellites;

c. Assembly of spacecraft whose final configuration exceeds the STS payload capability of an individual flight.

Each TDM was analyzed for operational requirements, facilities, hardware, and concepts. The objective of the accommodation needs task was to conceptually define the special support equipment required on the space station to provide the servicing needs of the TDMs.

Accommodation needs were defined by generating a servicing scenario, and then identifying the functional interfaces associated with each of steps in that scenario. Specific support equipment required to satisfy these interfaces were defined. Emphasis was placed on conceptual design of space station accommodation needs necessary to support each TDM. A definite trend toward support equipment commonality became obvious when the needs of all eight TDMs were compared. The conclusion arrived at indicated that major servicing systems could and should be designed with sufficient flexibility to accommodate multiple payloads.

Task 3 Programmatic Analysis - The primary objective of programmatic analysis task was to generate the plans, schedules, and cost analysis for each technology development missions.

Cost analysis supported TDM selection and time phasing prioritization. Cost/benefit assessment of all satellite servicing tasks was conducted to determine those tasks with the largest economic payoff. These are geosynchronous delivery, basing instrument facilities on the space station, low earth orbit servicing and delivery of satellites, and geosynchronous servicing.

TDM costs and schedules were developed and critical servicing elements (TMS, OTV, Servicers, etc.) were identified through TDM requirements and technology development analyses and cost and schedule estimates were derived for these elements. Most of the identified technology development issues were projected to have critical schedules. Specifically, early technology development of space based (reusable, resuppliable, repairable on-orbit) TMS and OTV vehicles are required to enable early capture of the major cost beneficial servicing missions.

2.0 MISSION REQUIREMENTS

The purpose of the Mission Requirements task was to identify the satellite servicing and maintenance capabilities, establish servicing tasks and scenarios (locations and methods of servicing), develop mission objectives for the specified servicing tasks, and establish the mission/system/hardware requirements necessary to perform the servicing scenarios. This purpose was accomplished by performing the following subtasks: 1) Establish an Evolutionary Technology Plan; 2) Derive Technology Development Mission objectives; and, 3) Derive Technology Development Mission requirements. The results of these task analyses are described in the following sections, 2.1-Evolutionary Technology Plan, 2.2-Technology Development Mission objectives, and 2.3-Technology Development Mission Requirements.

2.1 EVOLUTIONARY TECHNOLOGY PLAN

The objective of this task was to develop an evolutionary technology plan that identifies the satellite servicing tasks, servicing locations, and servicing concepts (servicing scenarios), and develops a technology demonstration test plan for the capabilities required to perform the servicing scenarios. This objective was accomplished by: 1) developing a satellite servicing data base of time phased satellite missions planned between now and the year 2000, and identifying the servicing needs and capabilities of candidate satellites; 2) establishing time phased satellite servicing scenarios, from the identified servicing tasks; and 3) determining the time phased technology/capability demonstration test plan. These three tasks are described in the following sections and form the basis of the Satellite Servicing Evolutionary Technology Plan.

2.1.1 Development of the Mission Model

The satellite servicing mission model is a composite of the mission models developed by NASA, Battelle, other contractors, and Martin Marietta Corporation (MMC) in-house studies. In addition it includes potential missions suggested through visits by MMC personnel to potential users. Although not included in the servicing mission model, those tasks encompassing the assembly, maintenance, and growth of the space station itself are also considered. The model was constructed in four steps: (1) Development of a mission model data base; (2) Assembling a composite mission model; (3) Developing an Affordable mission model from the Composite mission model using trade studies as shown in Figure 2.1.1-1; and (4) Using the Affordable Mission Model and estimated servicing intervals to arrive at the Satellite Servicing mission model.

2.1.1.1 Mission Data Base

The sources used in developing the mission data base were: Battelle's Outside Users Guide and Low Energy Models; NASA Space Systems Technology Model 80-81, Volumes I and III; Space Station Program Definition, Attachment A; Candidate Technology development Missions; Flight Assignment Baseline; National Space Club; AIAA Assessment; Gomersall Report; NASA/Washington Bionetics Report; and direct contact with the satellite user communities. The information obtained by these direct contacts is used as the most current source for updating this document.

As a result of these user contacts, concept data sheets for each mission were generated. These sheets were developed in close coordination with the cognizant satellite users, and include the mission objectives and description, orbital characteristics (including accuracy and tolerance if applicable), pointing requirements, and requirements for power, data/communication, and thermal considerations. The physical characteristics of the satellite are described in these sheets as well as operational and crew requirements and current servicing/maintenance concepts. These sheets were used in the development of the user capability requirements.

2.1.1.2 Composite Mission Model

The Composite Mission Model (CMM) consists of 389 separate missions identified in one or more of the twelve sources described in Table 2.1.1.2-1. Of the 389 missions over half come from Battelle's Outside User payload (P/L) High Model, '82, and the NASA Space System Technology Model, '80-'81, volume I. No restrictions were placed on incorporating a mission into the CMM; it was assumed that all desired missions, from any source whatsoever, could fly at the times indicated and that any technology problem would also be solved by those times. Table 2.1.1.2-2 presents a page from the Composite Mission Model. Each mission in the CMM was given a unique two-letter identification symbol.

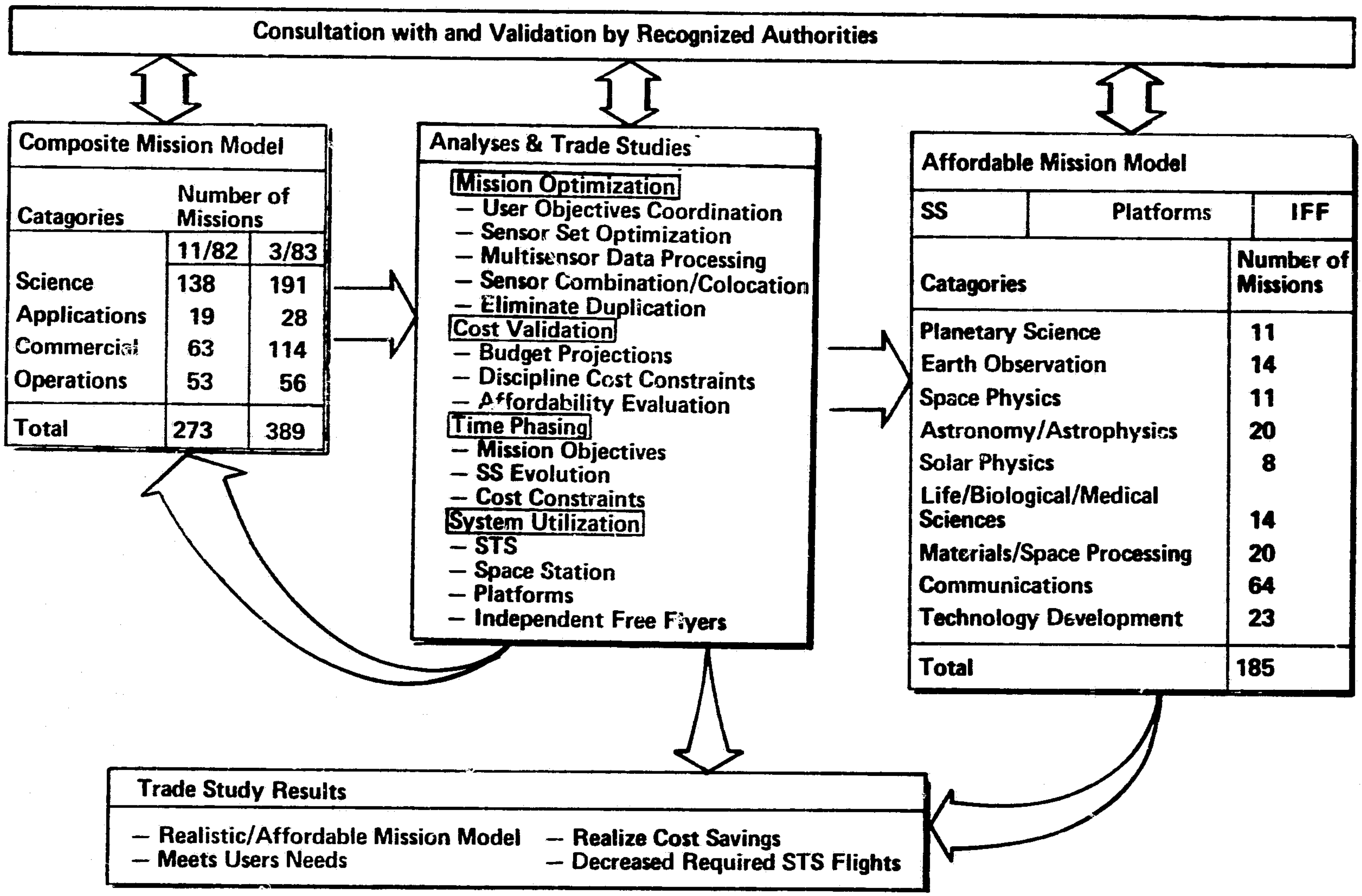

Figure 2.1.1-1 Affordable Mission Model Development

Table 2.1.1.2-1 Mission Sources for User Requirements Analysis

Symbol	Source
L	Battelle's Outside Users P/L Low Model, '82
H	Battelle's Outside Users P/L High Model, '82
E	Battelle's Low Energy Model '80
T	Space Systems Technology, Model '80-'81 NASA, Vol I
M	Space Systems Technology Model, '80-'81 NASA, Vol III
D	Space Station Program Definition, Attachment A, Candidate Technology Development Missions, '82
F	Flight Assignment Baseline, '80
N	National Space Club, '82
A	AIAA Assessment, '81
G	Gomersall Report, '82
B	NASA/Washington Bionetics Report, '82
U	Direct Contact With Outside Users

Table 2.1.1.2-2 MMC Composite Mission Model Science Class

PROGRAM ORG/NATION	STATUS / ID	CLASS	LAUNCH: SITE	LAUNCH: VEHICLE	LAUNCH: OTS	ORBIT: INCLIN (DEG)	ORBIT: ALT (KM/NM)	PHYSICAL PARAMETERS: MASS (KG/LB)	PHYSICAL PARAMETERS: LENGTH (M/FT)	PHYSICAL PARAMETERS: DIAM (M/FT)	MISSION SUMMARY: DUR (YRS)	MISSION SUMMARY: NO. OF SATS	MISSION SUMMARY: LAUNCH YEAR	MISSION SUMMARY: LIFE (YRS)	SERVICE	RETRIEVE	CONFIDENCE	SOURCE	LOD ENHANCE	DEL-RETRIEVE	SERVICING	SORTIE SUPPT	SPLY-STOW-FIX	OPS CNTL CNTR	LAB-TEST FAC	ASSEMBLY	STERILIZATION	COMM+DH	TETHERED SAT	SAFETY	FREE FLY PLAT	REMARKS
CXGT (X-Ray Telescope) NASDA, NASA, Joint	CA	S-4	KSC	STS							4	1 1	1993 1997	0			3	H		X	X											No backup designated
Very Long Baseline Interferometer (VLBI) MIT, NASA, JPL/U.S.	CF	S-4			OTS	45+	400-5000/216-2700			30.0/98.4	2+	1 1	1989 1990	1			2	ET		X	X					X		X				Ten year life desired.
Gravity Probe-B (GP-B) NASA-MSFC, Stan. U./U.S.	DS	S-4	VAFB	STS	OMS KIT	90	520/281	1530/3366	4.2/13.8	4.2/13.8		1	1992	1			2	TA		X	X											
Cosmic Background Explorer (COBE) NASA-GSFC/U.S.	DU	S-4	VAFB	STS		99 sun synch	900/486	1421/3126	4.8/15.7	4.4/14.4	1	1	1985	1			1	T		X	X											DELTA is backup.
Active Optics Technology NASA-ARC/U.S.	EM	S-4		STS													3	D							X							Several year lifetime required.
Orbiting Infrared Submillimeter Telescope (OIST) JPL/U.S.	EM	S-4		STS			700/378	10000/22000						10			4	M		X	X							X				
Infrared Interferometer NASA-ARC/U.S.	EO	S-4	KSC	STS		28-50	400-700/216-378	22500/49500						5			4	M		X	X					X		X				
Gravity Wave Interferometer NASA-GSFC/U.S.	EP	S-4		STS				16000/32500						1-5			4	M			X				X			X				
Coherent Optical System of Modular Imaging Collectors (COSMIC) NASA-MSFC/U.S.	EQ	S-4	KSC	STS	HLLV OTV	28.5	500/270	67000/147400						10			4	M		X	X					X		X				Initially LEO. Eventually GEO.
100-Meter Thinned Aperture Telescope (TAT) NASA-MSFC/U.S.	EM	S-4	KSC	STS	HLV OTV IUS	28.5	500/270	85000/187000						10			4	M			X					X		X				
Very Long Baseline UV/Optical/IR Interferometer NASA-MSFC/U.S.	ES	S-4	KSC	STS ETS		28.5	425/230	22850/50270									4	M		X	X					X		X				
Very Large Space Telescope (VLST) NASA-MSFC/U.S.	ET	S-4	KSC	STS E.T.		28.5	425/230	22850/50270						10			4	M		X	X					X		X				

The class or category (Table ..1.1.2-3) within which the mission fell was also indicated. Launch site, orbital and physical parameters, and mission schedule data for each mission are included in the CMM. If the mission description in the original source included an indication that some type of service or that a retrieval was necessary, this information was also included. Finally, a first estimate of the space station capability requirements is presented.

2.1.1.3 Affordable Mission Model - The CMM contained no restrictions on which missions were to be included. User capability requirements developed from such a model would be unrealistic in that the results would require an exceptionally high budget and would assume upwards of 70 non DOD satellite launches in a single year, many with almost identical objectives. To bring the CMM to a realistic basis, an Affordable Mission Model (AMM) was developed using the following groundrules:

- Each mission in each category is prioritized according to scientific objectives.
- Missions with similar scientific objectives are combined.
- A "realistic" budget is developed for each discipline/category and each mission is given a recommended "affordable" schedule (budget and spend plan).

The mission categories and the development of specific missions according to the above ground rules is shown below.

Planetary Science

These missions are based on a long range systematic strategy of exploration, reconnaissance, and missions to bodies in the solar system. The mission model also builds upon the experience gained from previous explorations.

Earth Observations

The missions selected dalt with the major objectives outlined for this science discipline. These objectives are to study upper & lower atmospheric processes and to observe land and ocean characteristics. Missions furnishing complementary data can, if used together, have synergistic effects. Combinations of missions were an important consideration in mission selection.

Space Physics

The general objective of space physics is to understand the fundamental physical processes involved in mans global and universal environment. Although the main thrust of the program is the advancement of space physics, the improvement in monitoring and prediction capabilities in the study of solar-terrestrial relationship is also very desirable.

Table 2.1.1.2-3 Composite Mission Model Program Classes

Science

S-1 Planetary Exploration
S-2 Earth Observation
S-3 Space Physics
S-4 Astronomy
S-5 Solar Physics
S-6 Life/Bio/Medical Sciences
S-7 Other

Applications (R&D)

A-1 Materials Processing
A-2 Other

Operations (Technology Development)

O-1 Satellite Servicing
O-2 Assembly of Space Structures
O-3 Fluid Transfer/Storage
O-4 Operating Platform
O-5 Launch Transfer
O-6 Propulsion
O-7 Spacecraft Control
O-8 Data Management & Communication
O-9 Electrical
O-10 Crew Systems
O-11 Thermal Control
O-12 Other

Commercial

C-1 Space Processing
C-2 Communications Satellite
C-3 Other

DOD (Classified)

D-1/D-4 Existing Programs
D-2/D-5 New Programs
D-3/D-6 Space Station Specific Applications

Astronomy

The missions selected were based on scientific priorities identified in the "Astronomy Survey Committee Report (1982)". The committee addresses the major scientific questions and objectives as defined in this report. It provides a broadbased approach using the full electromagnetic spectrum for both exploration and detailed study. Many of the programs are currently funded and will be developed during the 1980s and it is felt that the entire mission complement will be accommodated by funding projected through the 1990s. These mission sets are in accord with the recommendations of several astronomers actively pursuing major work in key areas.

Solar Astronomy

This proposed program essentially builds on the STS/Spacelab programs. The individual instruments would be flow as they are available and eventually integrated into the Advanced Solar Observatory (ASO). The ASO will have flexibility to evolve through configurations of increasing capability as new instruments become available. With the space station support, these changes can be accomplished on-orbit.

Life/Biological/Medical

All of the human research will be performed in the Health Maintenance Facility (HMF) which is to be located in the crew habitability module of the Space Station. A number of the equipment items required for routine and contingency medical support will have dual utility in basic biomedical research. The HMF is anticipated to evolve through four levels of support capability. Category I is provided by the Shuttle during buildup. Category II will be fully operational at the time longer duration manned missions are implemented. Categories III and IV (2000+) will be characterized by expanded research and medical support capabilities.

Materials Processing

The early emphasis of space station in the area of Materials Processing will be basic research. This country's knowledge base of processing phenomena in low-gravity environments is not broad enough to allow accurate prediction of those commercial processes that might prove effective in space. Therefore an extensive complement of research facilities will be included within the laboratory, and have included the laboratory module as one of the early components in the space station buildup.

Communications

Commercial communication satellite launch operations can be accomplished after the implementation space station Reusable Orbital Transfer Vehicle (OTV) capabilities. The OTV launch operations will become a significant space station benefit and are therefore incorporated into the mission set as early as possible.

Technology Development

The missions selected for the technology development discipline will cover a variety of space technology disciplines to illustrate the range of adaptability of the space station to these development endeavors.

2.1.1.4 Satellite Servicing Mission Model - The Satellite Servicing Mission Model was developed by assigning a service interval to each mission in the affordable Mission Model to estimate the support services and operations required by them. To facilitate this task, each of the applicable services and operations was given a code as indicated in Table 2.1.1.4-1. Also shown in this table are the normal service intervals discussed below. The Satellite Servicing Mission Model is shown in Table 2.1.1.4-2.

The service interval is the expected time between successive applications of the same type of service. These times vary for each type of satellite. For the purposes of this study an average service interval for each type of service is assumed, applicable to all satellites.

Depending on usage, the service interval for storable propellants can range from two to as long as ten years. For this study a four to five year service interval for storable propellants was assumed for geosynchronous satellites, and a 30 month interval for other satellites.

It is assumed that for those missions where it is applicable, cryogen resupply is performed every 18 months. Persent cryogen resupply is scheduled as often as every 6 months. The assumed service interval therefore appears to be near the upper bound of cryogen storage capability in the early 1990's.

The replenishment of expendables is mission peculiar, and their service intervals are treated accordingly.

Preventive maintenance is normally scheduled to be accomplished in orbit. However if the spacecraft is to be returned to the space station for other purposes this service will be performed there.

Decontamination includes the cleaning or re-coating of optical parts to maintain performance. A 24-month service interval is assumed for this operation. It is also assumed that decontamination must be accomplished at the space station.

Refurbishment is the total restoration of an item to its original state, i.e., a complete overhaul of the spacecraft. Refurbishment is scheduled in the hangar of the space station or returned to earth every four to five years, or when indicated in the mission description.

Table 2.1.1.4-1 Space Station Capabilities Functional Requirements

Functional Requirement	Code	Normal Service Interval
Assembly		
Hardware Build-up	A1	NA
Construction	A2	NA
Payload Mating	A3	NA
Resupply		
Fluid Transfer	P	30 months
Storable Propellant		(4-5-Years at GEO)
Cryogenci and Other Coolants	Y	18 months
Other Expendables	E	Variable
Orbital Transfer		
Delivery	D	NA
Retrieval	R	NA
Maintenance		
Preventive Maintenance		
Remote	M1	Variable
Space Station	M2	Variable
Decontamination	S	2-3 years
Refurbishment	B	3-5 years
Random Failure Repair		
Remote	F1	21 months
Space Station	F2	21 months
Mission Operational Services		
Instrument Alignment	I1	NA
Instrument/Payload Changeout	I2	3 years or user specified

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Table 2.1.1.4-2 Satellite Servicing Mission Model

Mission	Langley ID MMCX-	Year 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Astronomy																
Cosmic Background Explorer (COBE)	0001	RY S P PF2D		RY S PB D												
Far UV Spectroscopy Explorer (FUSE)	0002			D		R F2 S D	M1	RSD								
X-Ray Timing Explorer (XTE)	0003		F1		M1		F1									
Extremely UV Explorer (EUVE)	0004		RS P M2 D		RO S D		RS F2 D									
Gamma Ray Transient Explorer (GTE)	0005			D			P F1	M1		P F1						
Heavy Nuclei Explorer (HNE)	0006							ID1		F1						
Starlab	0007			SB I1 D		R F2 S D		RB I2 S D		[illegible] I2 D	F1					
Shuttle IR Telescope Facility (SIRTF)	0008			SB Y D		RY F2 SD	I2 Y	RB Y SD		R SY I2 F2 D						
Large Area Modular Array of Reflectors (LAMAR)	0009						A1 D		F1	R B P D			F1 P			
Orbiting Very Long Baseline Interferometer (OVLBI)	0010			A1 D	Y	F1 P	M1 Y	Y	F1 P	Y	F1 YP		Y	F1 P	Y	
Orbiting IR Submillimeter Telescope (OIST)	0011										I1 D	Y	F1 P	Y M1 I2	Y	F1 P
Faint Object Telescope (FOT)	0012	F1														
Space Telescope (ST)	0013		RB S D		F1	RS D		RB SD			RS M2 D		F1			
Adv X-Ray Astrophysics Facility (AXAF)	0014					D		F1 I2		RB I2 D		M1		F1		
Large Deployable Reflectors (LDR)	0015												A1 D	Y	RS F2 D	Y
Gamma Ray Observatory (GRO)	0016		F1		F1		F1 I2	M1		F1	F1	I2		F1	M1	

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Table 2.1.1.4-2 Satellite Servicing Mission Model (cont)

Mission	Langley ID MMCX-	Year 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Astronomy (concl)																
Coherent Optical System of Modular Imaging Collectors (COSMIC)	0017												A2 I1 D		RS F2 D	P
Thinned Aperture Telescope (TAT)	0018															A2 I1 D
Cosmic Ray Observatory (CRO)	0019											A1 D			P	
X-Ray Observatory (XRO)	0020									A3 D		F1				

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Table 2.1.1.4-2 Satellite Servicing Mission Model (cont)

Mission	Langley ID MMCX-	Year 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Solar Physics																
Solar Optical Telescope (JOT)	0200	F1		RB SP D	F1	P	R F2 S D									
Solar Soft X-Ray Telescope	0201		R1 E F2 s p d													
Pinhole Oculter Facility	0202	D			R F2 S P D		R F2 SP D									
Adv Solar Observatory	0203					A1 D		F1 P	F1		RB P I2 D		F1	P	F1	
Solar Shuttle Facility	0204		A1 D		F1 I2											
Solar Interplanetar Satellite	0205															
Solar Interior Dynamics Mission (SIDM)	0206															
Solar Coronal Diagnostics Facility	0207	RE F2 SP D		F1	P											

Table 2.1.1.4-2 Satellite Servicing Mission Model (cont)

Mission	Langley ID MMCX-	Year 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Space Physics																
Space Plasma Effects on Large S/C	0400		F2		F2		F2									
Large S/C Impact on Proximate Space Plasma	0401		F1		F1		F1									
Initial Solar Terrestial Obs (ISTO)	0403					A1 D	Y	R YS P F2 D	F1	R I2 YS D	Y P F1	RY S D	M1 P	RY SD	Y	RY S P F2 D
Geosynchronous Solar Terrestial Observatory (Geo-STO)	0404											A1 D	Y	RS YP F2 D	F1	RY I2 Y D
Very Large Radar	0405															
Origin of Plasma ir ‹ › Earth Neighborhood (OPEN)	0406														A1 D	
Adv Interplanetary Explorer (AIE)	0407								D							
Plasma Turbulence Explorer	0408												D		F1 P	
Chamical Release Module Facility	0409	F1		R B E D		F1		F1								

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Table 2.1.1.4-2 Satellite Servicing Mission Model (cont)

Mission	Langley ID MMCX-	Year 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Planetary																
Venus Radar Mapper	0101															
Comet Rendezvous	0102		D													
Mars Geochemistry/Climatology	0103															
Titan Probe	0104															
Mars Probe Network	0105											D				
Venus Atmospheric Probe	0106									D						
Lunar Orbiter	0107						D									
Comet Sample Return	0108							DR								
Main-Belt Asteroid Multirendezvous	0109										D					
Earth Approaching Asteroid Rendezvous	0110											D				
Saturn Probe/Orbiter	0111															

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Table 2.1.1.4-2 Satellite Servicing Mission Model (cont)

Mission	Langley ID MMCX-	Year 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Life and Biological Sciences																
Health Maintenance Laboratory	0617	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Botany	0616					D	E	E R1	E	E						
Vivarium and Life Science Lab	0618 0619					A2	4E	4E	4E	4E	4E	4E	4E	4E	4E	4E
Various Life/Biological Science Experiments		Same Services Indicated for Health Maintenance Laboratory, Vivarium, and Life Sciences Laboratory														

Table 2.1.1.4-2 Satellite Servicing Mission Model (cont)

Mission	Langley ID MMCX-	Year 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Earth Observation																
Feature ID & Location Exp (FILE)	0700															
Large Antenna Multifrequency Microwave Radiometer	0701	D A3		F1	F1											
Stereo Visual Imager	0702					A3 D		F1		F1						
Earth Radiation Budget	0703	A3 D		F1		F1		F1		F1						
Coastal Zone Color Scanner	0704	D A3		M1 P	F1											
Ocean Microwave Package	0705				A3 D		F1	F1								
Scatterometer	0706				A3 D		F1	F1								
Tethered Magnetometer	0707											Y	M2	Y	F2 Y	
Gravity Gradiometer	0708										D	Y	M1	Y	F1 Y	
Ocean Topography Exp (TOPEX)	0709			D		M1 P		P	F1	P	M1		P			
Geosynchrounous Satellite Intercalibration	0710	A3 D	R		D	R		D	R							
Thermal Imager	0711								A3 D	Y	R F2 S D	Y F1	R YS D			
WINDSAT (LIDAR)	0712				A3 D 2E	4E Y	4E F1	4E Y	4E F1 Y							
CLIR	0713	R F2 S Y D		R F2 S Y D												
Imaging Spectrometer	0714	F1 P	M1													

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Table 2.1.1.4-2 Satellite Servicing Mission Model (cont)

Mission	Langley ID MMCX-	Year														
		1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Earth Observation (concl)																
Microwave Radiometer	0715	F1 P	M1	P	F1		P F1									
Synthetic Aperture Radar	0716															
Active Microwave	0717								A3 D		F1	M1			F1	
Microwave, Passive, 100m	0718								A1 D	F1		M1			F1	

Table 2.1.1.4-2 Satellite Servicing Mission Model (cont)

Mission	Langley ID MMCX-	Year 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Material Processing Application																
SS Materials Processing Lab	0801		6E	6E	6E	6E	6E	6E	6E	6E	6E	6E	6E	6E	6E	6E
Various Missions		Same Service as SS Materials Processing Laboratory														

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Table 2.1.1.4-2 Satellite Servicing Mission Model (cont)

Mission	Langley ID MMCX-	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Commercial Communications																
Experiments Geostationary Platform	1001		D				P F1				P F1					
Search and Rescue	1002					P F1				P F1				P F1		
Orbiting Deep-Space Relay Station	1003								A1 D				P F1			
Intelsat VII	1004			DD	DD	DD	PP F1 DD F1	PP DD F1 F1	PP DD F1 F1	PP D F1 F1	PP F1 F1	PP F1 F1	P F1			
Telestat-K-N	1004	D														

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Table 2.1.1.4-2 Satellite Servicing Mission Model (cont)

Mission	Langley ID MMCX-	Year 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2006
Commercial Communication Satellites																
Telesat F/O	1004						D	D			P F1	P F1				
SBS F/O	1004				D	D	D	D	P F1	P F1	P F1	P F1				
SATCOM F/O	1004	D	D	D	D											
Telstar 3 F/O	1004			D	D	D		P F1	P F1	P F1						
Wester F/O	1004			DD	DD											
Advanced Wester-2	1004				D	D	D	D	P F1	P F1	P F1	P F1				
Tracking & Data Acquisition System (TDAS)	1004			D	D	D	D	P F1	P F1	P F1	P F1					
Galaxy F/O	1004		D	D	D	D	D									
Syncom F/O	1004				DD	DD										
G-Star F/O	1004				D	D	D	D	P F1	P F1	P F1	P F1				
SPC F/O	1004	D	D	D	D	D	D									
MSat	1004			D		D		P F1		P F1						
SBTS F/O	1004		D	D	D	D										
Mexsat F/O	1004		D	D												
Satcol F/O	1004			D		D		D		D						
Aussat F/O	1004			D	D	D	D	P F1	P F1	P F1	P F1					
Italsat F/O	1004		D	D												

Table 2.1.1.4-2 Satellite Servicing Mission Model (cont)

Mission	Langley ID MMCX-	Year														
		1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Commercial Communication Satellites (concl)																
Nordsat F/O	1004					D	D	D				P F1	P F1	P F1		
Arabsat F/O	1004		D		D											
Palapa F/O	1004	D	D													
Chicomsat F/O	1004	D	D	D	D	D	D	D	D							
Regional Comm Sats	1004	D	D	D	D	D	D	D								
Data Transmission Sets F/O	1004			D	D	D	D	P F1	P F1	P F1	P F1					
Banking	1004		D		D											
Mail F/O	1004					D	D	D				P F1	P F1	P F1		
STC F/O	1004			DDD	DDD			P P P F1 F1 F1	P P P F1 F1 F1							
DBS F/O	1004		DDD	D D D	DDD	DDD	DDD									
China DBTV	1004	D	D	D	D	D	D	D	D							
Canada DBTV	1004					D	D	D	D	P F1	P F1	P F1	P F1			

Table 2.1.1.4-2 Satellite Servicing Mission Model (cont)

Mission	Langley ID MMCX-	Year 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Commercial Materials Processing																
Electrophoresis (EOS)	1801	F1 F1	F2 F2	4 A3 4D F2 F2	3 A3 3D 4 F1	2 A3 2D 3 F1	F1 F1									
Monodisperse Latex Reactor	1802			2E F2	2E	2E F2										
MPS Commercial Development	1803					2E	2E									
MPS Commercial Production	1804					A3 D	2E	2E	2E	2E						

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Table 2.1.1.4-2 Satellite Servicing Mission Model (concl)

Mission	Langley ID MMCX-	Year 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Technology Development																
Low-Thrust Propulsion Tech	2011				P	P P										
Large Space Power System	2012				A1											
Solar Array Plasma Effects	2013			A3 D R												
Solar Pumped Lasers	2004						E	E								
Laser to Electric Energy Conversion	2005						E	2E								
Solar Panel Technology	2009			E												
Fluid Management Technology	2010	PY	P Y													
Antenna Range Facility	2016						E	E								
Laser Comm, Track, Range	2017				E	E										
Fire Safety Technology	2019	E														
Satellite Servicing Tech	2021		M2 F2													

No spacecraft has 100 percent reliability. Present designs of singly redundant spacecraft, extrapolated to the early 1990's, are expected to have a mean life of 36 months. It is assumed that repair/replacements of failed components will occur when the spacecraft is still operational. That is, when one of the redundant components fails it will be replaced before the backup also fails. If a combination of two redundant components has a mean life of 36 months, then one of them has a mean life in an excess of 20 months. This was rounded up to 21 months: the assumed mean time between repair/replacement of failed components.

2.1.2 Time-Phased User Needs Scenarios

The analyses of satellite servicing capabilities and technologies began with an assessment of the requirements imposed by individual missions. Initially, we considered some 389 mission; this number was reduced to 185 missions as discussed in section 2.1.1. Individual requirements were then combined, integrated, and time-phased into a unified set of user requirements.

User requirements were divided into four broad classes of servicing tasks with descriptive subtasks:

1) Assembly
   - o Space Station (Assembly/Modification)
   - o Large Spacecraft

2) Orbit Transfer
   - o Delivery
   - o Retrieval

3) Resupply
   - o Fluids - earth storable, mono propellant, bi-propellent
   - o Fluids - cryogens
   - o Solid Objects - logistics, raw materials

4) Maintenance
   - o Module Replacement
   - o Refurbishment
   - o Decontamination

These servicing tasks are described in detail later in this section.

From our analyses we found that assembly contributed only a small fraction of the total requirements. Orbit transfer and retrieval accounted for 32% of the requirements, propellant and consumables resupply accounted for 36%, and maintenance accounted for 25%. The mission category with the most requirements was commercial communications. This category, along with astronomy and earth observations accounted for two thirds of the total requirements in the time period between 1991 and 2000.
The servicing tasks can occur at any one of several locations, Table 2.1.2-1 lists the servicing tasks and cross references them with potential servicing locations:

1) <u>Space Station</u> - The mission payload is mounted to the interior or exterior of the space station.

2) <u>Berthed at Space Station</u> - A free flying payload has been transferred and berthed to the space station.

Table 2.1.2-1 Satellite Servicing Scenarios

		Servicing Locations				
	Servicing Tasks	Space Station	Berthed at SS	S/C In LEO User S/C	S/C In LEO SS Plat	S/C In HEO
Assembly	Space Station (Assembly/Modification)	X		X		
	Large Spacecraft	X	X			
Orbit Transfer	Delivery		X	X	X	X
	Retrieval		X	X	X	X
Resupply	Fluids – Earth Storable – Mono, Bi-Prop	X	X	X	X	X
	Fluids – Cryogen	X	X	X	X	X
	Solid Object – Raw Materials	X	X	X	X	X
Maintenance	Module Replacement	X	X	X	X	X
	Refurbishment	X	X	X	X	X
	Decontamination	X	X	X	X	X

3) Spacecraft In Low Earth Orbit (LEO) - The payload is attached to an unmanned carrier platform or a free flying satellite in LEO. The primary objective of a platform is to provide precise pointing low contamination, a very low-g environment, subsystem support, and the unique opportunity to support servicing of multiple payloads at one time. In both of these cases, the payload remains in its operational orbit during the servicing operation.

4) Spacecraft in High Earch Orbit (HEO) - The payload is in an orbit that is beyond the operational range of the Teleoperator Maneuvering System (TMS) and therefor requires a higher performance vehicle to accomplish the large inclination or altitude changes. As above, the payload remains in its operational orbit during the servicing operation.

To gain an insight into the frequency of servicing opportunities per year, a servicing capability requirements time-phasing analysis was undertaken. Using the servicing intervals described in the mission model section, the number of potential servicing opportunities for each subtask per year were calculated and graphed to give an overview of the user needs. The graph is found in Figure 2.1.2-1. This analysis covered the first ten years of the space stations operational life.

The time phasing of opportunities shows a rapid buildup in the first two years, followed by a relatively level period, and then a gradual decline. However, the decline is more probably due to uncertainty in estimating the out-year requirements than to an actual reduction in opportunities. Peak activity is 98 servicing opportunities per year, in 1997.

In the early years, the principal service required is orbit transfer and retrieval, while resupply opportunities gradually increase to represent the majority of opportunities in later years. Maintenance and repair opportunities increase very gradually throughout the decade.

2.1.2.1 Space Station Evolution - The starting point for this study is an early space station, therefore, a detailed evolution plan has been developed for MMC's recommended space station program option; a manned station operating at 28.5° in conjunction with several unmanned platforms. The proposed evolution plan is presented graphically in Fi^ure 2.1.2.1-1. The following commentary will present supporting rational on a year-by-year basis.

a. 1990 Implementation of unmanned station elements is initiated in the second half of 1990 with delivery of the energy section, habitability module including a category II Health Maintenance Facility (HMF), and a Teleoperator Maneuvering System (TMS). For the Shuttle Derived Vehicle (SDV) architectural option, delivery of these items would be delayed and combined in single launch with the items implemented in 1991.

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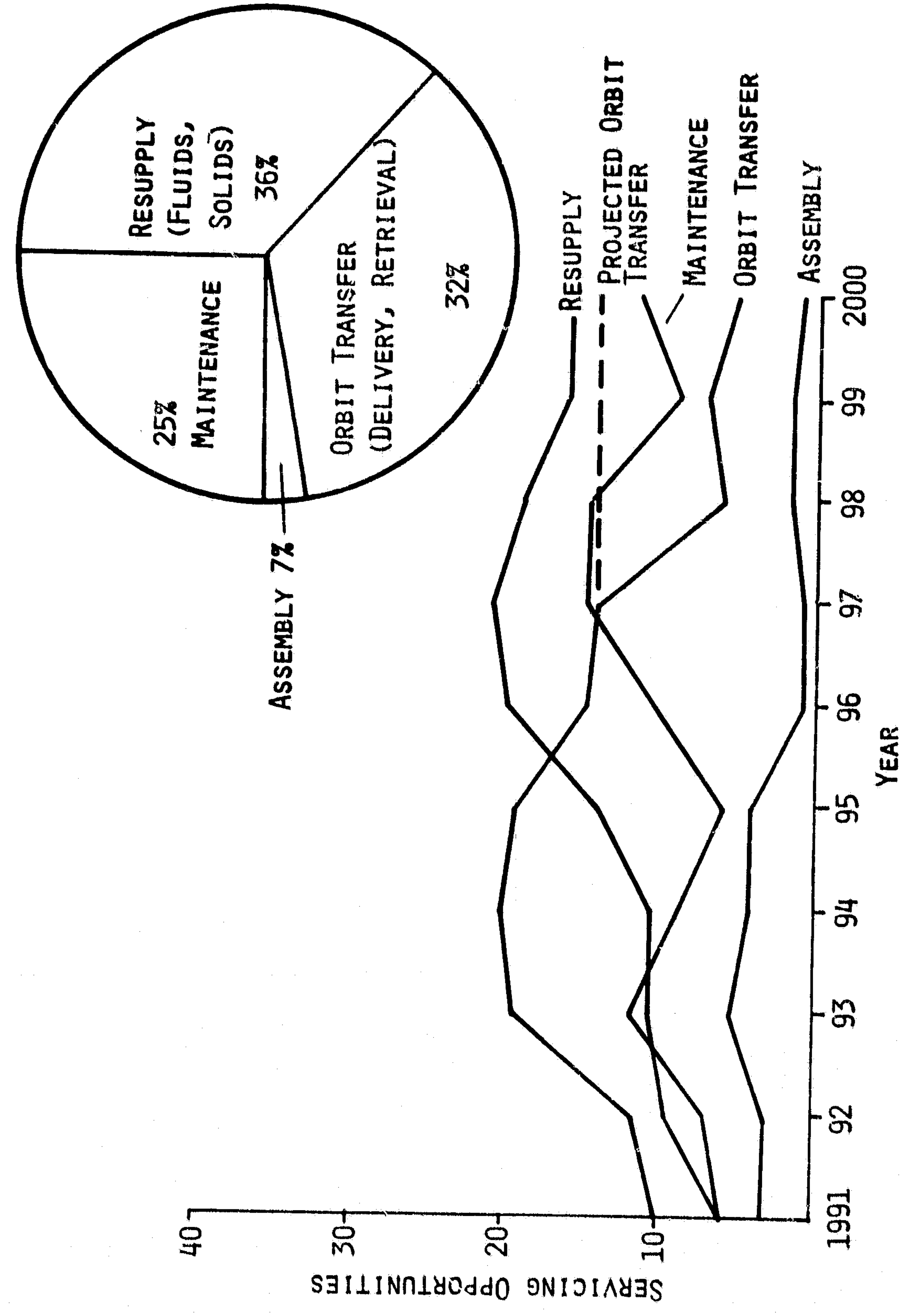

Figure 2.1.2-1 Time Phased Servicing Tasks

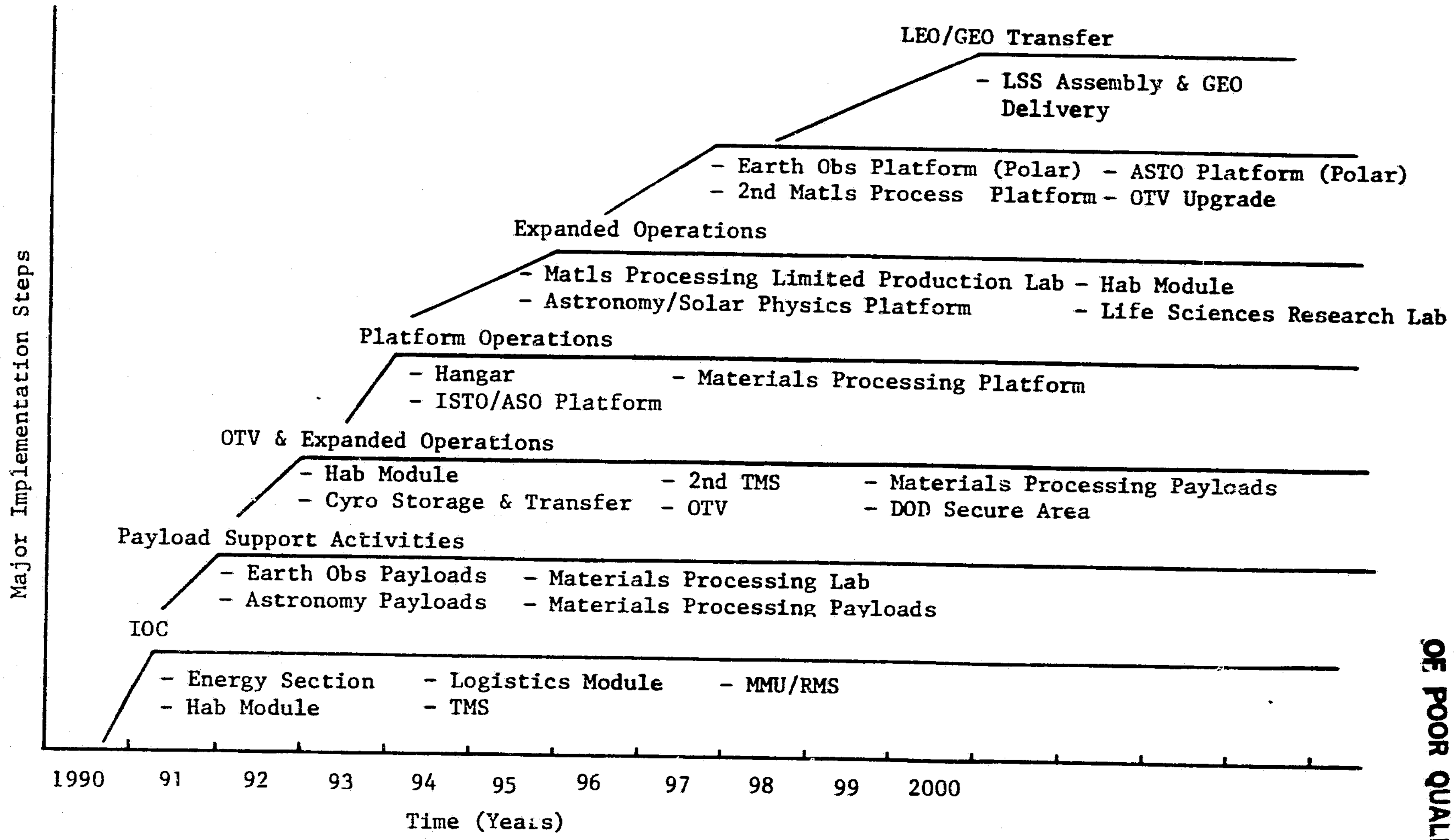

Figure 2.1.2.1-2 Recommended Evolution Plan

b. 1991 Space station initial operational capability (IOC) will occur early in 1991 with delivery of a logistics module, a Manned Maneuvering Unit (MMU), servicing robotics, and the initial crew of four people.

Following station checkout and a brief learning period, scientific payloads will be delivered for attachment to and operations from the station.

Toward the end of 1991, a materials processing (MP) laboratory will be implemented for MP research and development activities. Servicing and resupply of earlier free flying MP payloads operating in a 28.5° orbit will also be initiated using the TMS.

c. 1992 In preparation for the initiation of Orbital Transfer Vehicle (OTV) operations, a cryogen storage tank and a second TMS will be implemented. Because of the crew support for OTV operations, a second habitability module is implemented, followed by the retrievable OTV; and OTV delivery of NASA and DOD payloads to LEO and GEO will begin during the third quarter of the year.

An additional 2 MP payloads will be supported on the station for a total of four.

With availability of the OTV and associated increased DOD operations, it may be necessary to add a secure area or module at this time.

The high level of activity scheduled for this year precludes implementation of a hanger until early 1993.

The OTV activities will continue in subsequent years at a level of 1 or 2 OTV missions monthly.

d. 1993 Early in this year, hangar assembly will begin and continue intermittently through much of the year, interspersed with other activities.

The combined Initial Solar Terrestrial Observatory (ISTO)/Advanced Solar Observatory (ASO) platform will be implemented at a 57° orbit, with future servicing support from the 28.5° station via OTV transfer.

A MP platform and MP payloads will be implemented and begin operations in the vicinity of the station, and regular TMS resupply missions will be initiated.

e. 1994 The MP laboratory will be expanded to include a limited production facility which will allow increased production for the more promising processes without full commitment to a complete payload.

An Astronomy/Solar Physics platform will be implemented and operate in the vicinity of the station with continuous communications possible between the two. The physics payloads between 1994 and 2000.

f. 1995 A life sciences research module will be implemented to conduct plant and animal experiments. A third habitability module will be implemented to accommodate a total crew of 12 people.

g. 1996 A dedicated Earth Observations platform will be implemented in a polar orbit, and will be integrated and supported by the STS since our recommended OTV will not be capable of 28° to 90° orbit plane transfer.

h. 1997 A second MP platform may be required at this time to accommodate commercial payloads whose processes were previously developed in the MP laboratory and limited production facility. This platform will operate in the vicinity of the station and be supported with regular resupply missions using a TMS.

An OTV upgrade may be appropriate at this point to either increase payload deliver capability or to add a thrust control capability which will allow the OTV to carry sizable, but flexible payloads or platforms from LEO to GEO.

i. 1998 The earth observations Passive Microwave payload will require on-orbit assembly support at or near the space station, and will be transported to GEO by the OTV.

At about this point in time, crowding of the available GEO communications satellite orbit may require assembly of a multi-payload platform at the station and subsequent OTV delivery to GEO.

j. 1999 During this period, the GEO-STO space physics platform 2000 will require assembly at the station and OTV delivery to GEO.

Similar support will be required by the space physics Very Large Radar.

With this evolution plan, the space station will be able to support the servicing tasks described in detail in the next four sections.

2.1.2.2 Assembly - The Assembly task consists of two subtasks; (1)Space station assembly and modification, and (2)Large spacecraft assembly. The space station assembly sequence has been covered in the evolution description in Section 2.1.2.1. Large spacecraft assembly is the assembling of a spacecraft too large to be brought up on one shuttle flight. Depending on the final size of the vehicle, it will be assembled in an unpressurized protected hangar or at a designated assembly site elsewhere on the space station.

2.1.2.3 Orbit Transfer - Satellite delivery and satellite retrieval are the two subtasks that make up the Orbit Transfer servicing task. The delivery of a payload to its operational orbit will occur either during its initial deployment or redeployment after the payload has been returned to the space station for servicing. Payload retrieval consists of returning the payload to the space station for servicing or for a return to earth. The delivery and retrieval subtasks are integral in the majority of the other servicing tasks.

2.1.3.4 Resupply - The resupply servicing task in defined by three subtasks: (1) Fluids earth storable, mono, and bi-propellents; (2) Fluids - cryogens; and (3) Solid Object Supply - raw materials. The two fluid resupply subtasks are similar only in the fact that fluids are being transferred. The manner in which they are transferred, stored, and brought up to the space station requires different technologies and requirements. The fluids are used either as propellents for the delivery vehicles (TMS's and OTV's) and payloads or as coolants for the experiments. The solid object supply consists of the replenishment of raw materials for materials processing and life sciences payloads.

2.1.2.5 Maintenance - The maintenance task consists of module replacement, refurbishment, and decontamination. The module replacement subtask involves the upgrade, preventative maintenance, and corrective maintenance of the user payloads on a modular level. Refurbishment involves major repair or upgrade of a payload on a systems level. Decontamination has potential uses in the satellite servicing realm such as cleaning lens and sensors and replacing or recoating degraded surfaces.

2.1.3 Technology Survey

A technology survey was conducted to determine if the satellite servicing time phased capability needs identified through the mission data base, task assessment and mission scenario analyses were compatible with the technologies presently being developed. The purpose of the technology survey was to evaluate the status of technology underway to address each capability need and to determine how the need can be demonstrated by a series of time phased demonstration tests. These include ground tests, shuttle sortie tests and tests on the manned space station.

The results of the technology survey were used to develop a Capability Demonstration Test Plan (CDTP) (reference Figure 2.1.3.2-1), outlining the sequential ground, Shuttle and space station tests to satisfy identified capability needs. This plan was the third element of the Evolutionary Technology Plan and was derived from the other two elements. The first element is the derived Space Station Satellite Servicing Mission Model analysis which identified servicing tasks and locations and supported development of mission scenarios. The second element was identification of satellite servicing and maintenance capability scenarios. As servicing capability needs are identified through servicing task/location and mission scenario analyses, the technology survey was conducted to explore the status of technology efforts that would support servicing needs on the early space station.

2.1.3.1 Servicing Technology Assessment

An initial analysis of satellite servicing and space station needs led to a initial summation of technologies that could serve as a reference point to conduct the survey. This list of technology categories is shown on Table 2.1.3.1-1.

After further study, it was determined that this group of technologies should be reduced to include only those directly related to satellite servicing and those space station elements directly supporting satellite servicing capability needs. These technology categories are shown in Figure 2.1.3.1-1. These technologies are not considered all inclusive, they were selected to focus the survey effort and develop a finite Capabilities Demonstration Test Plan.

The scope of research conducted in the technology survey included consultation in-house with Martin Marietta personnel currently performing satellite servicing activities, NASA centers, DOD and aerospace industry firms, and review of past servicing technology documentation. Current Martin Marietta satellite servicing contracts and IR&D efforts were reviewed to evaluate their contribution to meeting identified technology capability needs. These include: The Solar Maximum Repair Mission; a Shuttle mid-deck fluid transfer experiment, the Cryogenic Fluid Management Facility design (and planned future Shuttle flights), the Teleoperator Maneuvering System (TMS)

Table 2.1.3.1-1 Space Station/Satellite Servicing Technologies Requiring Development

- Cryo Storage, Liquefaction and Transfer
- Optical Systems Assembly, Refurbishment, Test, and C/O
- Mono/Bi Propellant Fluid Transfer
  - Zero Spill
- S/C Radar Systems
- ET Propellant Scavenging/-Storage
- Advanced EVA Suit
  - Non Contaminating
  - Higher Suit Pressure
- Operational Techniques (Technology Transfer - Ground Operations vs Space Operations Technologies)
- Reusable Vehicle Refurbishment
  - Power System Replacement/-Refueling
  - Unscheduled Maintenance
- Pressurized Work Area
- Aero Braking
- Reusable OTV & TMS
- Compatible Interface Concepts
- Checkout Concepts
- Servicer Concepts
  - Robotics
  - Remote Control
  - Artificial Intelligence
- Solar Array Maintenance in Orbit
  - Space Station
  - Remote Satellites
- Large Space Structure Assembly Concepts

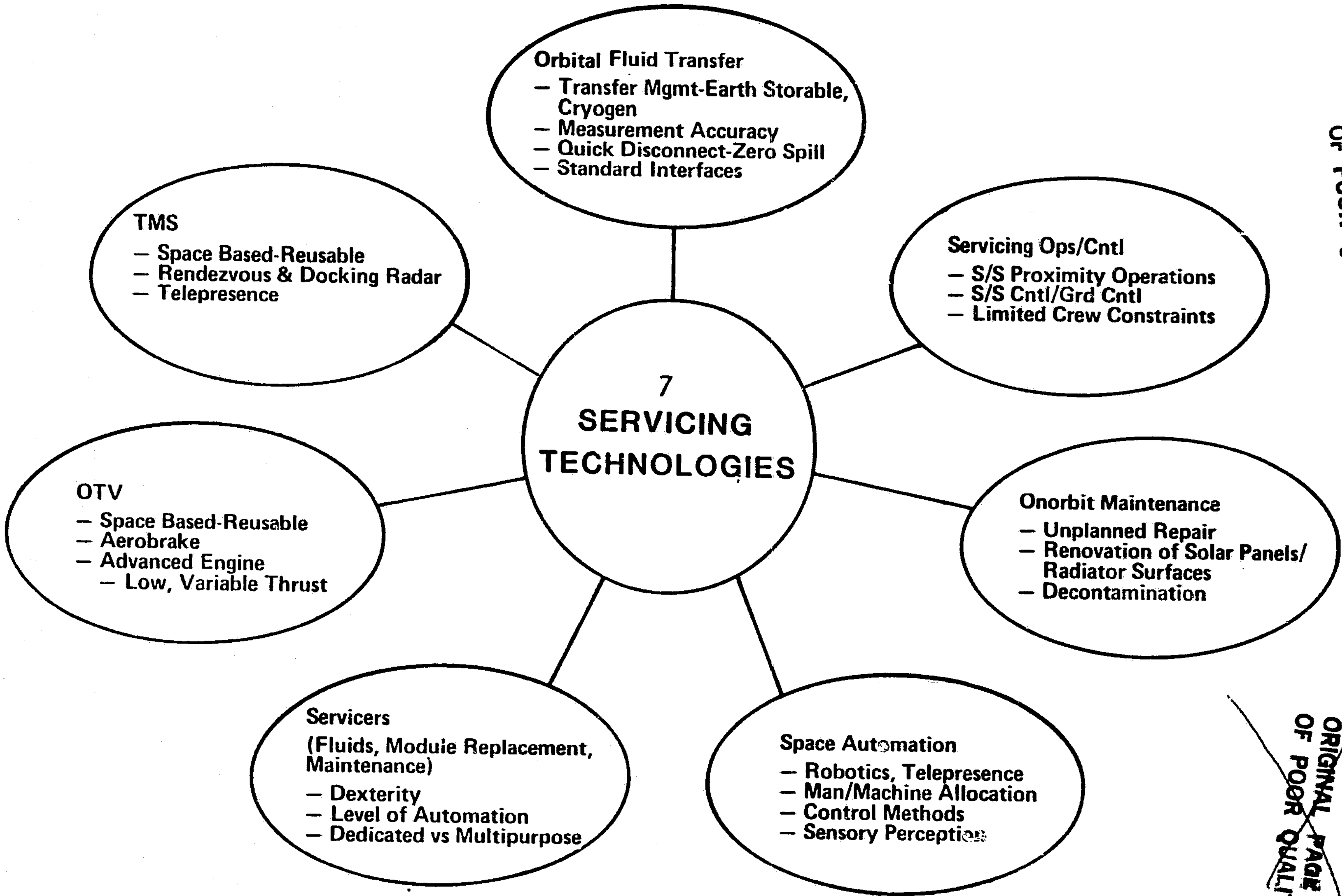

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Figure 2.1.3.1-1 Satellite Servicing Technology Development Survey Categories

study, and various space automation (robotics, telepresence, automated intelligence) designs and studies. To augment this information, teleconferences were held with satellite system project offices at Marshall Space Flight Center, Langley Research Center, Goddard Space Flight Center, Johnson Space Center, and Lewis Research Center. Teleconferences were also conducted with a wide range of aerospace industry firms including General Dynamics, McDonald Douglas Astronautics Company, Boeing Company, Rockwell International, Lockheed Missile and Space Company, and Hamilton Standard. A broad range of past and current satellite servicing concept studies reports and documents were researched to comprehend past efforts in these technology areas.

The result of this research effort was the identification of definitive sub-technologies for each of these areas. The technologies; and their associated sub-technologies are in Table 2.1.3.1-2. Also, general recommendations in each of the key technologies is given below.

a. Fluid Transfer - Work in this area is underway. We recommend that the same level, if not an increased level, of research is maintained to resolve the identified issues before the space station era.

b. Teleoperator Maneuvering System - Contracts are underway for an initial study. We expect the TMS to be operational in the late 1980's.

c. Orbital Transfer Vehicle - Due to the utility and cost benefits of space station based GEO delivery, we recommend the OTV be developed early enough to capture GEO missions in the early phase of the space station.

d. Servicers - Not much attention has been given to servicers. The servicer design is contingent on advances in fluid transfer, space automation, and on-orbit maintenance technologies. These areas must mature before servicers can be developed.

e. Space Automation - Work in this area has been underway for some time now but a more intensive level of effort is needed if space automation is to support space station servicing operations. Since a limited number of crewmembers will be doing the work normally done by many on earth, space automation will play a key role in the servicing operations. An automation decision process must be defined to; (1) identify the most important issues, (2) prioritize these issues, and (3) expedite the resources needed to resolve these issues.

Table 2.1.3.1-2 Satellite Servicing Technologies

Orbiter Fluid Transfer	- Transfer Management - Earth Storable, Cryogen - Initial Conditions in Receivers - Measurement Accuracy - Quick Disconnect Zero Fill - Standard Interfaces
Teleoperator Maneuvering System (Assumed Available)	- Space Basing - Maintainable, Reusable - Standard Interface/Flexible Grapple for Stacking
Orbital Transfer Vehicle	- Space Basing - Reusable - Changes of Major Systems, Engines, Avionics - Payload Operations - Buildup of Delivery, Servicing Stacks - Advanced Engine - Low, Variable Thrust (Delivery/-Retrieval of Large, Deployed Spacecraft) - Aerobrake - Aero-Maneuvers, Reusable (Repair/-Replace)
Servicers - Fluids - Earth Store-able/Cryogen - Solid Object - Modules, Raw Materials	- Servicer Dexterity - Degree of Automation
- Maintenance - Repair, Refurbish, Decontaminate	- Dedicated vs Multipurpose
Space Automation	- Man-Machine Task Allocation - Control Methods - Sensory Perception - Robotic/Telepresence Mechanisms
On-Orbit Maintenance Technology	- On-Orbit Unplanned Repair of non-Modular Components - On-Orbit Refurbishment - Renovation of Solar Array Panels/Radiator Surfaces - Decontamination - Energetic Oxygen Sputtering
Servicing Operations	- Space Station Proximity Operations Around Complex Structures/Tethered Elements - Transfer of Control from Space Station Mission Control to Ground Control - Management of Multiple, Complex Operations with Minimum Space Station Crew

f. On-Orbit Maintenance Technologies - Past programs have advanced modular replacement technology (Multi-mission Modular Spacecraft (MMS)/Space Telescope (ST) but more investigation is needed. Decontamination and spacecraft refurbishment require an increased level of research.

g. Servicing Operations Control - This area is an extension of the work already underway for the Space Transportation System (STS) program. Areas such as autonomous control and space station proximity operations are of particular interest.

2.1.3.2 Capabilities Demonstration Test Plan

The Capabilities Demonstration Test Plan is the culmination of the technology effort conducted for this study. The purpose of this plan is to present status of where the scientific community is in developing servicing capability needs and where the emphasis should be for future research. The plan shows a logical progression of research efforts and demonstration tests that are recommended to advance capability in each technology area to support user needs on the early space station.

The technology plan first lists the technologies and sub-technologies followed by the corresponding demonstration test or research efforts: Ground based tests and studies; tests conducted aboard the space shuttle; and tests to be carried out at the Space Station. Next to each technology activity is a symbol that indicates what phase it is in. The key for these symbols follows:

C - Work is Complete
O - Research Effort is Ongoing
P - Research/Tests are Planned
R - Research/Tests are Recommended

The Capabilities Demonstration Test Plan is presented in Table 2.1.3.2-1

Table 2.1.3.2-1 *Capabilities Demonstration Test Plan*

TECHNOLOGY	GROUND TESTS	STS TESTS	EARLY SPACE STATION TESTS
Orbital Fluid Transfer	One-g Bench Tests (C)	NASA - Crew/Propellant Interfaces (STS 7/9) (P)	TMS/Logistics Module Fluid Transfer Tests (R)
	Apollo 14 Tranfer Test (C)	MMC - IR&D, Storable Fluid Management Demonstration	OTV/Cryogen Storage Tank Test (R)
	MMC - IR&D, Orbiter Supply System Design (C)	LeRC/MMC - CFMC Flights (3-7) (P)	Transfer Control System Test and Demonstration (R)
	IR&D, Propellant Transfer (O)	NASA - Hydrazine Transfer Experiment (P)	
	LeRC/MMC - Design of Cryogenic Fluid Management Facility (CFMF) (O)	MMS to Mark I Propulsion Module Transfer (R)	
	JSC/MSFC - Propellant Delivery to Orbit (P)	TMS/Mark II Propellant Transfer (R)	
	- ET Scavenging	TMS/"Battleship Tank" Fluid Transfer Tests (R)	
	- Aft Cargo Carrier	OTV/"Battleship Tank" Fluid Transfer Tests (R)	
	- OMS Capture	Fluid Transfer Control Algorithm Development (R)	
	NASA - Quick Disconnect Coupling Zero Spill Study (P)		
	Propellant Transfer Procedure Development (R)		
Reusable Teleoperator Maneuvering System	TMS Assumed Available		

Table 2.1.3.2-1 (cont)

TECHNOLOGY	GROUND TESTS	STS TESTS	EARLY SPACE STATION TESTS
Reusable Orbital Transfer Vehicle	GD - Centaur Design Development (O) MSFC - Phase A OTV/ACC Study (P) Ground Based Reusable OTV Study (R) Space Based Reusable OTV Study (R)	Galileo Flight 1985 (P) Ground Based Reusable OTV Flight (R) Space Based Reusable OTV Flight (R)	Reusable OTV "Battleship Tank - Fluid Transfer Tests - Aerobrake, Avionics, Engine Refurbishment, Replacement Tests (R)
Servicers	MSFC/MMC - Integrated Orbital Servicing Study (IOSS) (C) LeRC/MMC - Remote Orbital Servicing System (C) MSFC - Modified IOSS/MMS Module Service (1984) (P) MSFC - Teleoperator Human Factors Study (P) MSFC - Simulation and Hardware Experiment (1984-85) (R) Servicer Design and Development - Fluid (ES and Cryogen) - Module Replacement - Maintenance	MSFC - IOSS/MMS Cargo Bay Service Demonstration (1987) (P) - Free Flight (Remote) Demonstration (P) Servicer Hardware Orbiter Bay Demonstration (1987-88) (R) Servicer Demonstrations in Cargo Bay (R) Servicer Refurbishment and Reuse Demonstration - Fluid (ES and Cryogen) - Module Replacement - Maintenance (R)	Servicer Demonstration(s) - At space station - From space station (R) Servicer Refurbishment and Reuse Demonstration (R)

Table 2.1.3.2-1 (cont)

TECHNOLOGY	GROUND TESTS	STS TESTS	EARLY SPACE STATION TESTS
Space Automation			
• Mechanisms			
- Reach, Dexterity, Tip Force, Signal/Power	MMC - Scaled Shuttle Manipulator Arm (C) MMC - Protoflight Manipulator Arm (C) MSFC/MMC - Integrated Orbital Servicing System (C) MSFC - Modify IOSS to Service MMS Module (Ground Test-84) (P)	IOSS/MMS Servicer Demonstration (87) (P)	
• Control Methods	MMC - IR&D Control Methods (O)		
- Control Mode Selection Position/Rate Controller	MSFC/MMC - Laboratory Testing (O) ITA (O)		
- Dual Arm Controller			
• Fixed Programmed Control	MSFC - IOSS/Modified MMS-Module Service (84) (P) MSFC - Teleoperator Human Factors Study (P)	IOSS/MMS Cargo Bay Service Demo (87) (P) Free Flight Demo (88) (P)	
• Servicer/Transfer Vehicle Control System Integration	Simulation & Hardware Experiment (84-85) (R)	Orbiter Bay Demo (87-88) (R)	

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Table 2.1.3.2-1 (cont)

TECHNOLOGY	GROUND TESTS	STS TESTS	EARLY SPACE STATION TESTS
<u>Space Automation</u> (cont)			
• Man Machine Task Allocation	MSFC/MIT - ARAMIS (O)		
- Task Assessment	MSFC - THURIS (P)		
	ROBSIM Task Simulation (R)		
- Man-Machine Optimum Capabilities	Components Mockup Lab Demonstrations (R)	Protoflight System Demonstration (R)	Engineering Model System Demonstrations (R)
- Task Allocation Trade Studies			
• Sensor System Integration	AFWL/DARPA/MMC - Intelligent Task Automation (ITA) (O)		
- Stereo, Laser, Video, and Tactile	- Stereo Vision, 3-D Laser Scanner		
	- Automated Intelligence		
	- Tactile Sensing		
	- Dual Arm		
	ARMY/MMC - Robotic Locating System (O)		
	- Sensor Systems Cargo Handling		
	- Laser, Infrared Imaging		
	MSFC/MMC - Autonomous Video Rendezvous and Docking System (O)		
	- Phase II - Physical Simulations (R)	Flight Experiment (1985)(R)	Flight Experiment (R)

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Table 2.1.3.2-1 (cont)

TECHNOLOGY	GROUND TESTS	STS TESTS	EARLY SPACE STATION TEST
On-Orbit Maintenance Technologies			ORIGINAL PAGE IS OF POOR QUALITY
o Module Replacement	LaRC/MMC - Remote Orbital Servicing System (ROSS) (Unplanned Servicing) (C) GSFC/MMC - Solar Maximum Repair Mission Design (SMRM) (O)	GSFC/MMC - Solar Maximum Repair Mission (P)	
	Robotic/Telepresence Maintenance Servicing Concepts Studies (R) - Unplanned Repair - Space Station Attached/ Remote	On-Orbit Maintenance Technique Demonstrations - Cargo Bay - Free Flying	Maintenance Technique Demonstrations - Array Refurbishment, Replacement - Radiator Repair, Replacement (R)
o Decontamination			
1. Environmental/Effects Data			
. Model Refinement/ Verification	- Space Computer Prog. Support/Spacelab Analysis (MMC/MSFC) (O) - Contam. Outgassing IR&D (MMC) (O)	- Space Computer Program Verif. Study (MMC/AF (O/P) - OSS-1 Contam. Mon. Package Data Analysis (GSFC) (O/P)	- Systems Level Modeling/Flt Data Comparison Analysis (R)
. EVA/MMU Induced	- EVA Suit Outgassing Tests (JSC) & Effluent Analysis (Ham. Std.) (C)	- Solar Max Repair Mission Monitor (GSFC/MMC) (P)	- EVA Analysis/Flight Monitoring (R)
. Fluid Leak Flow	- Vacuum Test (R) - Scattering Cross Section Tests (R)	- Flight Test-Sim. Leak/ Monitor (R)	- Servicing System Tests/ Monitor Env. (R)

Table 2.1.3.2-1 (cont)

TECHNOLOGY	GROUND TESTS	STS TESTS	EARLY SPACE STATION TESTS
o Decontamination (cont)			
. Propulsion System	- Surface Effects Characterization Study (AF/RPL) (P) - Engine Effluent Dep. Effects Tests (AEDC) (C/O)	- Plume Mapper Experiment - STS-7 (ESA) (P) - Propulsion System Flight Contamination Test (JPL Proposal) (R)	- Servicing System/Tests/ Monitor Env. (R)
. Fluid Leak Effects	- Transfer Fluid Effects Test (R) - Analysis of Induced Degradation (R)		
. Hardware Outgassing	- Materials Characterization (AFWL/LMSC) (O) - Contamination Outgassing IR&D (MMC) (O)	- IECM O&M Data Analysis (MSFC) (O)	- Test/Analysis/Flight Monitor Servicing H/W (R)
2. Control Methods			
. Cleaning External Surfaces	- Energetic Oxygen Cleaning Tests (C) - Cleaning Method-R&D/Design/ Test (R)	- Flight Experiments of Viable Options (R)	- Advanced Cleaning Concepts - Remote Systems (R)
. Environmental Monitoring	- Low Cost Realtime Degradation Monitor Development (R)	- IECM O&M Data Analysis (MSFC) (O)	- Flight Surface Degradation Monitor (R)
. Refurbishment Methods	- Surface Cleaning Technique Ground Test (R)	- SMRM Thermal Blanket/Module Replacement (P) - Refurbishment Tests (Thermal/Optics/Solar Arrays) (P/R)	- Flight Expt-On-Orbit Cleaning Kit (R)

Table 2.1.3.2-1 (cont)

TECHNOLOGY	GROUND TESTS	STS TESTS	EARLY SPACE STATION TESTS
. Protective Measures	– R&D/TESTS: Contamination Minimization Methods (R)	– Flight Experiments: Cold Traps, Purge Concepts, etc. (Simulated Transfer Fluid Leak Sources)	– Implement Abatement Concepts/Monitor (R)
3. Space Environment Impacts			
. Atomic Oxygen Degradation	– Ion Beam Gun Improvement Test (MMC/MSFC) (O) – Ion Beam Gun Facility Development (P) – Materials Screening Tests (P/R) – Test Facility Experiments (JSC/Aerospace/LMSC/etc) (O) – Oxygen Resistant Materials Development (R)	– Flight Experiments (MSFC/JSC/AFSD) (C/P) – LDEF (P) – SMRM Materials Evaluation (GSFC/MMC) (P)	– Long Term Exposure Experiments (R)
. Long Term Exposure	– Accelerated Env. Effects Test Method Development (R)	– LDEF (P) – Evaluation of Returned S/C Materials-SMRM, ST, DOD, etc. (R/P)	– Realtime Monitor Package Development (R) – Exposed Materials Sample Arrays (R)

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Table 2.1.3.2-1 (cont)

TECHNOLOGY	GROUND TESTS	STS TESTS	EARLY SPACE STATION TESTS
Servicing Operations/ Control	STS Payload Deployment (O)	STS Cargo Bay Fluid Transfer Operations (Earth/Storable/ Cryogen) (P)	Selected Precursors to Demonstrate Control of Servicing Operations At and Remote from Space Station (R)
	Combined STS/Ground Control of Space Operations (O)		
	Semi-Autonomous STS Operations (O)		
	Space Station Proximity Operations Control Concepts (R)	STS Payload Delivery Operations (O)	
	Control Console Design/ Development (R)	STS Retrieval/Repair Operations (SMRM) (P)	
	Autonomous Operations Concepts Study (R)	STS On-Orbit Large Payload Assembly Operations (R)	

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2.1.3.2.1 Orbital Fluid Transfer

Orbital Fluid Transfer is a technology area of express concern to NASA. Technology efforts related to earth storable fluids are specifically separated from cryogen efforts in this plan primarily because of the fact that requirements for each were seen to be different due primarily to the thermal control requirements of cryogen.

As shown on Table 2.1.3.2-1, for earth storable fluids Martin Marietta, under an IR&D effort, is preparing to assist NASA in conducting a storable fluid transfer demonstration on an upcoming sortie flight, using water as a reference fluid. NASA is planning a hydrazine transfer experiment using an EVA activity in the cargo bay. To further storable fluid technology development, propellant transfer procedure development is recommended. In the STS, some logical fluid transfer experiments are recommended. One experiment would involve transfer of fluids from the MMS to the Mark I propellant module and later on a demonstration transferring fluids using the TMS and Mark II. To prepare for TMS operations at the space station, we recommend a test using TMS and a hardened battleship storage tank to demonstrate resupply capability prior to space station tests. Again, as fluid transfer is projected to be a completely automated process, a fluid transfer control algorithm demonstration should be a part of the Shuttle TMS fluid transfer demonstration. These transfer control system, logistics module, and TMS fluid transfer tests must be conducted at the space station also as system level precursor TDMs.

For cryogen fluids, Lewis Research Center has contracted with Martin Marietta to design a Cryogenic Fluid Management Facility designed to serve as an experiment platform for cryogen transfer problem resolution. Several CFMF Shuttle flights are planned. Although not directly related to transfer, JSC/MSFC are combining to issue a study contract related to propellant delivery to orbit of both cryogens and fluids to explore cryogen delivery to orbit, using ET Scavenging and the Aft Cargo Carrier, and including capture of bi-propellants from the Orbital Maneuvering System (OMS). As with TMS, OTV/Battleship Tank fluid transfer tests are recommended to be demonstrated on the Shuttle prior to space station demonstration. Again, as for TMS, a series of cryogen tests, including demonstration of a fully automated cryogen transfer system, OTV and cryogen storage tank transfer and space station cryogen storage tank fill demonstrations are recommended.

2.1.3.2.2 Reusable Teleoperator Maneuvering System (TMS)

Although TMS was assumed available for the purpose of the study, requirements analysis conducted for TDM definition reflected the need for a space based, reusable TMS. To ensure cost effective orbit transfer and other space station support operations, it is recommended that the TMS be based at the space station, and be refuelable and maintainable on station. TMS will operate remote from space station and will require also the capability to rendezvous, mate and conduct various servicing operations. Some form of autonomous capability or man-in-the-loop (telepresence, hybrid system) system is required to ensure successful TMS operations. Numerous studies have been conducted and NASA is planning now to commit soon to design and development of a TMS. Recommend that planning and particularly design of the TMS be structured to accommodate evolution of the initial TMS to one capable of conducting servicing operations at the space station.

2.1.3.2.8 Reusable Orbital Transfer Vehicle

As with TMS, requirements analysis results reflect the need for an OTV that is space-based and reusable. For orbit transfer operations requiring high energy transfer vehicle, most studies indicate significant fuel (and cost) savings will accrue from application of an aerobrake on the OTV. Various aerospace industry firms, including Martin Marietta, have conducted concept and feasibility studies on aerobrake configurations. In addition, transfer of large deployed satellite systems appears to dictate the requirement for an advanced engine providing low acceleration loads to transiting spacecraft.

As shown on Table 2.1.3.2-1, General Dynamics has a high energy upper stage (Centaur) under development for transfer of the Galileo spacecraft in 1985. Marshall Space Flight Center (MSFC) is planning a Phase A study effort to examine OTV options which could be launched into low earth orbit using an Aft Cargo Carrier (ACC). It is recommended that a ground based reusable OTV be designed and tested on the ground and on STS prior to design and development of a space based reusable OTV. The OTV will be required to demonstrate capability of resupply at the space station from cryogen storage tanks and to demonstrate refurbishment capability, all as system level precursors to specific TDMs.

2.1.3.2.4 Servicers

Servicers will be required for resupply and maintenance tasks remote from the space station. These servicers will require varying levels of space automation technology applications and various degrees of flexibility for operations. Maintenance servicers must await development of space maintenance capabilities, such as unplanned repair, renovation of space borne surfaces (arrays, radiators) and decontamination technology, development.

In the past, Marshall Space Flight Center (MSFC) contracted with Martin Marietta to design and build the In-orbit Satellite Servicing (IOSS) unit, a preprogrammed, automatic, single arm servicer, designed for "planned" servicing. A Remote Orbital Servicing System study was conducted for Lewis Research Center, a study designed to examine the problems of conducting "unplanned" servicing.

MSFC is planning to conduct a study designed to modify the IOSS and using selected elements of the MMS, develop and ground test a module servicer. They are planning to demonstrate this servicer in cargo bay experiments in the late 1980s, followed by free flight remote demonstrations. MSFC is also planning, in the near future, to conduct a study entitled "Teleoperator Human Factors Study," which is essentially a study designed to analyze the automation aspects of satellite servicing.

Several studies are recommended for inclusion in an evolutionary development plan for servicing. Servicer design and development studies for the various types of servicers is recommended. These studies may conclude that either multi-purpose or dedicated servicers will be required. In either case, it will be a logical process to qualify them with appropriate Shuttle tests. Similarly, these same sets of servicers must be qualified and demonstrated as system level precursors at the space station.

2.1.3.2.5 Space Automation

An analysis of the requirements for satellite servicing has indicated that automation will play a major role in servicing systems as automation technology continues to expand and mature. Early space station activities will be dominated by manual operations, (both EVA and IVA), in and close to the space station. As the development of the space station continues, however, automated systems technology will be integrated into the overall system with increasing frequency.

The case for the use of automation in space is based upon the assumption that, in the long term, the performance of certain functions will be less costly using an automated system than using a man to do the same task. Automation is intended to augment and increase the capabilities of the human in space rather than totally replacing the human. One of the key issues confronting researchers in the automated systems area is how to rationally and systematically determine which tasks would benefit from automation, and the specific degree of automation that is required. The question is difficult for two reasons. First, much of the analytical and empirical data required for making such a decision, (based upon the current state-of-the-art), is not available. Further research and development is required to develop criteria for quantifying automation capabilities and to assess man/machine tradeoffs. Secondly, the tradeoff between man/machine will not be a static set of numbers, but time-varying as automation technology advances.

Some of the key automation issues are categorized in Table 2.1.3.2-1. The major issue areas are:

- o Mechanisms
- o Control Methods
- o Man-Machine Task Allocation
- o Sensor System Integration

The significance of each of these areas including technical sub-issues and relevant research and development efforts, (completed, ongoing, planned, and recommended) is discussed in additional detail below.

Mechanisms

The question of mechanism design for servicing systems can be discussed at several different levels ranging from the design of individual joint actuators to the optimum number of degrees of freedom for a single manipulator arm, or even the number of manipulators required for a given servicing system. However, compared to other servicing technologies, this area is quite mature as demonstrated by the fact that space qualified manipulator systems have been designed and built. Most notable of these is the RMS built by SPAR SYSTEMS of Canada, already proven on Shuttle flights. In addition, Martin Marietta has delivered two systems to MSFC; the IOSS, (Integrated Orbital Servicing System), and the P-FMA, (Proto-Flight Manipulator Arm). The IOSS is a single arm, 6-DOF, preprogrammed system optimized for radial and axial, (referenced to the docking probe axis), servicing tasks. The P-FMA uses a technology very similar to the IOSS arm, but has an additional degree-of-freedom and greater kinematic range. At the level of basic mechanical system design, the primary questions currently being investigated include improvements in actuator and power train design, more accurate joint sensors, and the use of lighter weight structural elements, such as composite materials, for the manipulator links. Other key areas of mechanism research include the number and ordering of joints, i.e., the kinematic configuration, dexterous end-effector designs, and the advantages and applications of multiple arm configurations.

Control Methods

The question of control mode selection is one of the most important in servicing technology since it encompasses both operator-intensive control systems, (where the operator explicitly inputs desired trajectories via hand controller inputs), and supervisory control systems where the operator initiates and supervises automated sequences. Other aspects of the servicing question addressed under this topic area include servo algorithm development, path planning/obstacle avoidance algorithms, and tradeoffs in computation distribution between the servicer and remote control station. Ongoing work in these areas is being conducted at MSFC using the IOSS and

P-FMA, at LaRC using two UNIMATE PUMA 600 manipulators, and at Martin Marietta under both IR & D D75D and the Intelligent Task Automation (ITA) contract, an AFWAL/DARPA sponsored effort. Sufficient data is not currently available to allow tradeoffs between control mode options to be conclusively evaluated. While a large amount of work has been performed in the past utilizing the primary control mode options, autonomous and operator intensive, (operator intensive modes include rate control, position control, position control with force feedback, and, as a subset of position control, exoskeletal control), little has been done in the way of conducting parametric comparison tests to establish performance rankings for different generic tasks and operating conditions, (e.g., different time delays). R & D work to establish concise tradeoffs in performance, sensor requirements, and computational requirements will be required and should include both ground based and orbiter bay experiments.

Other important issues involved in control mode selection include the coordinated control of multiple arm systems, and the integration of servicer and transfer vehicle control systems. Coordinated multiple arm control has received very little attention in the past, but has obvious payoff value in a servicing scenario. The question of servicer/transfer vehicle control system integration is somewhat speculative since a need for such integration has not been demonstrated. Depending upon the type of spacecraft being serviced, however, it seems apparent that the transfer vehicle attitude control system could function more effectively if it had access to servicer system force and torque information. Dual arm control is being investigated at Martin Marietta under IR&D D75D and ITA. The question of servicer/transfer vehicle control system integration will be investigated under Martin Marietta IR&D D75D in 1984.

Man-Machine Task Allocation

The major goal of work being performed on man machine task allocation is to provide a unified methodology for analyzing a given task, (or set of tasks), and assessing the degree to which automation technology should be applied to yield an optimum mix of man and machine. To achieve this goal, several parallel efforts are required. One effort must address a unified method for assessing and describing tasks. This will require the establishment of a set of generic tasks from which more complicated tasks can be derived. For example a module removal task might be composed of four bolt removals and one generic slide-in, slide-out box removal. At these levels, such generic tasks are easily transferred to laboratory mockups which can be used to develop accurate measures of relative performance. Work along these lines was started under the Automation, Robotics and Machine Intelligence Systems (ARAMIS) contract and will be pursued in more depth in the THURIS, (The Human Role In Space), study.

A second major effort is required to establish, in rigorous, quantified terms, the performance tradeoffs between various mixes of man and machine. This can be done in several ways. Ground testing can be accomplished using actual hardware or an integration of hardware and computer simulation. At this time hardware demonstrations are planned at several NASA centers, (primarily LaRC, MSFC, JSC), during the 1984-85 timeframe. In addition, Martin Marietta will integrate both kinematic and dynamic manipulator models developed under the ROBSIM program, (funded by LaRC), with hardware hand controllers under IR&D project D75D in 1983-84.

As a follow-on to these ground based activities, STS flight demonstrations are recommended for the resolution of questions not addressable in a 1-g environment. At this time, the structure and timeframe for initial flight demonstrations is being examined at both MSFC and JSC.

Sensor System Integration

Regardless of the control mode implemented on a servicing system, sensors will play a major role in assuring task accomplishment. A diverse set of sensors is required to overcome the need for absolute knowledge of relative positioning and alignment between the spacecraft that is being serviced and the servicer. Two basic categories of sensors are required, imaging sensors, and sensors capable of measuring force and torque data. Imaging sensors can be used for a variety of purposes. In a man intensive system, either mono or stereo vision is required to provide viewing of the worksite for the operator. In a Martin Marietta laboratory, a Fresnel stereo system is used for this function. An imaging capability can also be used in autonomous applications although a considerable increase in complexity is involved if scene interpretation is required. The use of both stereo vision and 3-D laser scanners are being investigated under the ITA program.

In the performance of actual tasks, force/torque and tactile information is used to compensate for the lack of precise alignment information. This is utilized in two basic ways. First, actual force and torque data can be fed back to the operator, either to the hand controller, or as displayed information. This same data can also be incorporated directly into the servo algorithms for an autonomous system. The use of force feedback, man-in-the-loop, control systems was investigated at Martin Marietta in the early 70's. While the results were promising, the impact of transmission time delays was not investigated.

2.1.3.2.6 On-Orbit Maintenance Technologies

On-orbit maintenance includes planned and unplanned repair operations, refurbishment of space station or satellite surfaces and decontamination operations. The technology survey of satellite system developers/operators, NASA, DOD and industry revealed that technology development in this area is extremely limited in some areas at this time.

The development of module replacement capability is essential for conduct of corrective maintenance both at the space station and remote from it. Planned corrective maintenance will require design of replaceable modules for satellite elements, such as pressurants, batteries and instruments. Module replacement will be accomplished by retrieval of a spacecraft from its operational orbit and replacement at a servicing port (hangar) on the space station, or by transport of a module servicer from space station to the satellite.

Referring to Table 2.1.3.2-1, Langely Research Center contracted Martin Marietta to conduct studies on the Remote Orbital Servicing System, a manipulator system with two anthropomorphic arms on a carriage capable of rotating 180 degrees. The ROSS was designed for unplanned maintenance operations. Goddard Space Flight Center (GSFC) is planning, with Martin Marietta providing system engineering support, to conduct a repair mission on the Solar Maximum spacecraft. The mission, scheduled for completion in 1984, will be conducted from the STS. An astronaut, using the Manned Maneuvering Unit, will fly out to capture and stabilize the Solar Max spacecraft. The STS will be positioned to enable retrieval by the RMS and attachment in the STS cargo bay. The mission will include both planned and unplanned maintenance. The modular attitude control system, one of the three design replaceable components of the Multi-mission Modular System (MMS), will be replaced. The unplanned maintenance event is the replacement of the main electronics box (MEB) of the Solar Maximum Observatory. The Solar Maximum Repair Mission will provide heritage for future space station repair operations. For required maintenance operations remote from the space stations, we recommend the initiation of robotic/telepresence maintenance servicing concept studies. These studies must lead to design, development and test of the concepts and of servicing equipment on STS and as precursor TDMs on the early space station.

Decontamination of space based elements is a technology area requiring extensive analysis and development. In Table 2.1.3.2-1, technology survey results indicate significant efforts are underway in the areas of monitoring and analyzing contamination data, and additional technology development recommended to determine contamination sources and accumulation rates. In the areas of actual decontamination outlined under Control Methods on Table 2.1.3.2-1, the absence of any significant development is apparent. Studies, development and test of both cleaning of contaminated surfaces and refurbishment of deteriorated surfaces are recommended. At this point in time, most spacecraft designer are driven to build in heavy contamination control shields for surfaces expected to become contaminated in the space environment.

2.1.3.2.7 Servicing Operation/Control

Satellite servicing operations will be complicated by many factors including crew size constraints, mission complexity, high activity levels, and space stations proximity operations in complex physical structures, that will likely include tethered elements. Space station operations will be built on the heritage provided by previous Skylab experience and on evolving STS operations.

Servicing operations will be the stressing types of operations on the early space station. Deployment of mated transfer vehicles and spacecraft to be delivered to orbit will require new forms of proximity operations, to prevent damage to space station elements and to preclude contamination of surfaces. This operation and many servicing operations will be conducted semi-autonomously, requiring high levels of visibility and command/control of automated processes.

Ongoing and planned Space Shuttle operations are establishing many satellite servicing precedents. Payloads have already been deployed from the STS to operational orbits, with high energy upper stages. In the near future, fluid transfer experiments will be conducted in the STS cargo bay, paving the way for future STS propellant and pressurant resupply operations, including both earth storable and cryogen resupply experiments and actual missions. Another STS servicing operation is the Solar Maximum Repair Mission, discussed previously in paragraph 2.3.4.3.6. These ongoing and planned servicing missions, conducted in space, will contribute significantly to the space servicing data base.

It is recommended that several servicing operation studies and preliminary designs be initiated in the same time frame as the space station architecture is developed. Space station proximity operations control concepts, specifically related to satellite servicing, must be developed to enable conduct of servicing operations. Requirements analysis indicated that control consoles for TMS, for OTV, for space station RMS and other servicing/service support elements will be needed. Design/development of those consoles and related equipment/procedures must be initiated in a timely manner to support servicing. Similarly, both space station autonomous operations concept studies and studies dealing with handoff of control from the manned station to space station ground control (for remote operations) must be initiated. On STS, many precursor servicing operations can (and will) be conducted. It is recommended that most, if not all, system level precursor TDMs be demonstrated using STS, prior to their demonstration at the space station.

2.1.3.2.8 Conclusions

The technology survey revealed no technology area wherein technology development was not already underway. All required technology development is shown to be extentions of technology already underway. As shown in Section 4.0, programmatic, analyses reflect the need to ensure that the pace of OTV and TMS development proceeds on a schedule that will enable high benefit to cost ratio missions; i.e., GEO delivery and LEO delivery and servicing missions, to be captured during the early space station era.

2.2 TECHNOLOGY DEVELOPMENT MISSION OBJECTIVES

The user mission requirements dictate what capabilities the space station must provide in order to accommodate the users satellite servicing needs. The first step in accommodating these needs is to develop Technology Development Mission (TDM) objectives for the early space station satellite servicing operations. Objectives were developed for each of the servicing task scenarios identified in Section 2.1.2; Assembly, Orbit Transfer, Resupply, and Maintenance. To further describe these objectives, system level objectives were developed to represent the next level of detail. Taking this procedure of developing lower level objectives one step further, detailed objectives were derived. In this manner the mission objectives can be satisfied when all the detailed objectives have been met.

In addition to the objectives developed for the servicing task scenarios, objectives were also developed for common servicing functions: Remote servicing, manned servicing, and rendezvous systems.

2.2.1 Assembly Objectives

The assembly objectives were developed for two subtasks; space station assembly/modification and large spacecraft assembly on orbit. The space station objectives were geared toward validating the technologies, operation and designs needed to assemble a space station. These objectives are found in Table 2.2.1-1. The objectives large for spacecraft assembly are found in Table 2.2.1-2 and will demonstrate the space station capability to assemble a large spacecraft (larger than the payload capable of being carried in on shuttle mission) in orbit.

2.2.2 Orbit Transfer Objectives

The objectives developed for the Delivery and Retrieval subtasks in the Orbit Transfer servicing task are very similar and were therefore grouped under one mission objective; Demonstrate the capability to deliver/retrieve spacecraft to and from operational LEO and GEO orbits and to and from the manned space station. These objectives are found in Table 2.2.2-1.

2.2.3 Resupply Objectives

The mission objectives for the resupply servicing task is to demonstrate the capability to supply/resupply spacecraft and the manned space station. The objective covers the replenishment of consumables: Fluids-propellants, cryogenics, and other; and solids used for materials processing and life sciences payloads. This objectives will be carried out either by a space station crewmembers on extravehicular activity (EVA) or intravehicular activity IVA or remotely via a servicing vehicle. The objectives are found in Table 2.2.3-1.

Table 2.2.1-1 Servicing Objectives - Space Station Assembly/Modification

Mission Objective	Demonstrate Capability to Assembly Evolving Space Station and Modify/Expand Elements			
System Level Objectives	Demonstrate Capability to Rendezvous, Align and Dock Space Station Elements	Demonstrate Capability to Attach/Detach Space Station Elements	Validate Support Systems/ Tools Required for Assembly	De De as
Detailed Objectives	Validate STS Dock with Space Station Core Element Validate Standard Docking Interface with STS/Space Station Core Validate Rendezvous, Alignment Docking at Coorbiting and Remote Platforms with STS, TMS, using EVA (MMU, EMU) Demonstrate Coordination/Handover to Control of Operations between Manned Space Station Control Center and Space Station Ground Control	Validate STS RMS (Improved RMS) Capability to Attach Initial Space Station Elements Validate Space Station RMS Capability to Transfer Elements from STS to Assembly Point Validate Tether Connections and Tethered Element Deployment, Operations Validate Coorbiting and Remote Platform Assembly (with STS, TMS, using EVA (MMU, EMU) Validate Concepts and Operating Techniques for Expanding/Growing Space Station Elements; Power Module, Radiator, Storage Facilities, etc.	Validate EVA Tools, EMU, MMU Handrails, Hand Holds, Foot Restraints, Lighting Aids Validate Space Station RMS, Control Console(s), Space Crane (Cherry Picker) Attachment, RMS Track and RMS Operations Validate Use of TMS, MMU, EMU for Assembly Support at Coorbiting and Remote Platforms Validate Checkout Equipment, Control Consoles for Checkout Equipment	Va De tu Op Va Re Mo Ma Co Sp

ication

ation and Modify/Expand Elements

to	Validate Support Systems/ Tools Required for Assembly	Demonstrate Capability to Deploy Folded Structures as required	Demonstrate Checkout of Completed Assemblies On Orbit
oved ch d ly or e r	Validate EVA Tools, EMU, MMU Handrails, Hand Holds, Foot Restraints, Lighting Aids Validate Space Station RMS, Control Console(s), Space Crane (Cherry Picker) Attachment, RMS Track and RMS Operations Validate Use of TMS, MMU, EMU for Assembly Support at Coorbiting and Remote Platforms Validate Checkout Equipment, Control Consoles for Checkout Equipment	Validate Procedures for Deploying Folded Structures in close proximity Operations Validate Capability to Retract and Add Expansion Modules as required at Manned Space Station and Coorbiting and Remote Space Station Platforms.	Validate Checkout Equipment, Control Consoles at Master Control Center and at Remote Control in EMU/Space Crane (Cherry Picker) Validate Checkout Procedures using Manned Spacecraft Control Center for Checkouts within RF Line of Sight and Transfer to Space Station Ground Control for Checkout beyond Space Station Line of Sight Validate Removal of Assembly Equipment, Transfer and Securing at Stowage Points

Table 2.2.1-2 Servicing Objectives - Large Spacecraft Assembly On Orbit

Mission Objectives	Demonstrate Capability to Assembly Large Spacecraft (Larger than One Shuttle Mission) On Orbit			
System Level Objectives	Demonstrate Capability to Store Interim Elements	Validate Support Systems, Tools for Assembly at Manned Space Station	Validate Repair of Interior Elements Prior to Final Assembly	Dem Mat cra
Detailed Objectives	Validate Transfer of Initial Element(s) from STS to Interim Storage Locations, Space Station RMS, TMS Validate Storage Interface with Space Station, Hangar, Tether Validate checkout procedure for initial elements	Validate Space Station RMS, RMS Track Operations, RMS Control Console (in Manned Space Station Control Center) Validate EVA Tools, MMU, EMU/Space Crane (Cherry Picker), Handrails, Handholds, Foot Restraints	Validate capability to conduct repair operations on failed Components, Modules prior to Assembly Validate Final Checkout Processes following Repair and Prior to Interim Storage	Val Fin fro Poi Val Ele Usi EMU/ Val Ele of Con Ver Dep

ly On Orbit

raft			
ystems, at on	Validate Repair of Interior Elements Prior to Final Assembly	Demonstrate Capability to Mate and Assemble Spacecraft Elements	Demonstrate Capability to Checkout Assembled Spacecraft
tion rations, e (in on	Validate capability to conduct repair operations on failed Components, Modules prior to Assembly	Validate Transfer of Final Spacecraft Element from STS to Assembly Point	Validate Checkout Equipment, Control Consoles at Space Station Master Control Center and at Remote Control in EMU/Space Crane (Cherry Picker)
, MMU, herry , Hand- ints	Validate Final Checkout Processes following Repair and Prior to Interim Storage	Validate Alignment of Elements and Mating Using S/S RMS, EVA (MMU, EMU/Space Crane)	Validate Removal of Assembly Equipment, Restowage of Transfer Vehicles, Securing of Assembled Spacecraft
		Validate Assembly of Elements Under Control of Manned Space Station Control Center	
		Verify Capability to Deploy Folded Structures	

Table 2.2.2-1 Servicing Objectives - Orbit Transfer (Delivery, Retrieval)

Mission Objective	Demonstrate Capability to Deliver/Retrieve Spacecraft to and from Operational LEO and GEO to and from the Manned Space Station			
System Level Objective	Demonstrate Capability to Stack Transfer Vehicles/Spacecraft	Demonstrate Capability to Load Stack with Propellants	Demonstrate Deployment of Stack to Remote Reboost Position	Demonstrate Capa to Deliver Space to Operational O
Detailed Objectives	Validate Movement of Transfer Vehicles (TMS/OTV) to Mating Position on Space Station using Space Station RMS Validate Mate of Transfer Vehicle(s)/ Spacecraft using (Space Station RMS, EVA (MMU/Space Crane, Control Consoles)	Validate Capability of Space Station RMS to Transfer Stack to Propellant Stroage Area Validate Propellant Loading: - Power Stack Down - Connect Fluid, Electrical Umbilicals - Load Vehicles - Validate Load Accuracy - Monitor Residuals - Disconnect Umbilicals Validate Checkout of Orbit Transfer Stack - Power Stack Up - Conduct Complete Checkout of Stack	Validate Space Station RMS Transfer of Stack to Deployment Site Validate Space Station RMS Deployment of Stack from Space Station Validate TMS Transfer of Stack to Orbital Boost Position Validate Space Station Control Center Capability to Control Vicinity Envelope Operations	Validate Capabil Final Preboost S Checkout Validate Remote Ignition (TMS, O Validate Transfe Mission Control Manned Space Sta Control to Space Station Ground C trol Prior to lo of RF Line of Si Validate Deliver Spacecraft to Co Operational Orbi Validate Remote of Spacecraft fr Delivery Vehicle Validate Remote Capability of Sp craft/Delivery V (Return of Nonop tional Delivered craft or Spacecr be Retrieved

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trieval)

to and from Operational LEO and GEO Orbits and			
nstrate Deployment tack to Remote ost Position	Demonstrate Capability to Deliver Spacecraft to Operational Orbit	Demonstrate Return of Stack from Operational Orbit to Space Station	Demonstrate Destack, Berthing of Retrieved S/C, Reusability of Transfer Vehicles
date Space Station Transfer of Stack eployment Site date Space Station Deployment of k from Space ion idate TMS Transfer Stack to Orbital st Position idate Space Station trol Center Capa- ity to Control inity Envelope rations	Validate Capability for Final Preboost System Checkout Validate Remote Engine Ignition (TMS, OTV) Validate Transfer of Mission Control from Manned Space Station Control to Space Station Ground Control Prior to loss of RF Line of Sight Validate Delivery of Spacecraft to Correct Operational Orbit Validate Remote Demate of Spacecraft from Delivery Vehicles Validate Remote Mating Capability of Spacecraft/Delivery Vehicles (Return of Nonoperational Delivered Spacecraft or Spacecraft to be Retrieved	Validate Remote Demate of TMS/OTV for Retrieval Operations Using both (as required) Validate Remote Mate of TMS and Retrieval Spacecraft (as required) Validate Remote Remate of TMS/Spacecraft to OTV (as required) Validate Remote Reignition of Transfer Vehicle for Return to Space Station Vicinity Validate OTV Aerobrake Operations (as required) Validate Retransfer of Control to Manned Space Station within RF Line of Sight Validate Space Station Vicinity Operation Control of TMS Transfer of Delivery STack to Space Station RMS	Validate Space Station RMS Capability to Grapple Stack. Transfer to Servicing Area. Validate RMS Transfer of Retrieved Spacecraft to Berthing Post Validate Checkout, Repair of OTV/Aerobrake (Reusable OTV) Validate Checkout, Repair Refueling of TMS, Transfer to Berthing Post

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Table 2.2.3-1 Servicing Objectives - Resupply (Fluids - Earth Storable/Cryogenic, Modules - Raw Mater

Mission Objective	- Demonstrate Capability To Supply/Resupply The Manned Space Station And Spacecraft - Locally And Remotely .			
System Level Objective	Demonstrate Resupply Support To Space Station	Demonstrate Capability of Resupply Vehicles	Demonstrate Resupply Operations for Spacecraft In Operational Orbits	
Detailed Objectives	Validate Space Station RMS Support To Berth And Transfer Servicers Validate RMS/and MMU/EMU/Space Crane capability to resupply raw materials to Manned Space Station Elements	Validate Reusability Of Cryogenic Fluid Servicer. - Verify zero spill, accurately measured, transfer of cryogens from Space Station storage tanks to servicer - Verify checkout refurbishment tasks to insure reuseability Validate Earth Storable Fluid Servicer - Fluid transfer - Post mission checkout, repair Validate Solid Object/ Module Replacement/Raw Material Servicer - Materials transfer - Post Mission Checkout Repair Validate Capability to Stack Servicers for Single Mission Multiple Servicing	Validate movement of transfer vehicle(s), servicers to assembly, stacking position with Space Station RMS Validate mating, standard docking interfaces with TMS/OTV Validate transfer of Servicers Stack to propellant/solid object loading post(s). Validate loading of Servicers and transfer vehicles - Materials transfer - Propellants Validate checkout of Servicer stack	Validate tra Servicer(s) orbit by tra Validate tra control from Mission Cont Station Grou Validate rem TMS Servicer (as required Validate rem Servicer wit Validate Rem of Spacecraf remate of TM OTV (as requ Validate ret transfer veh Space Statio Validate ref berthing on Station

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Earth Storable/Cryogenic, Modules - Raw Materials)

upply The Manned lly And Remotely .		
les	Demonstrate Resupply Operations for Spacecraft In Operational Orbits	
ility luid spill, easur- of m n s to kout t ure fer pair Object/ ent/Raw er ansfer Checkout ility to for Multiple	Validate movement of transfer vehicle(s), servicers to assembly, stacking position with Space Station RMS Validate mating, standard docking interfaces with TMS/OTV Validate transfer of Servicers Stack to propellant/solid object loading post(s). Validate loading of Servicers and transfer vehicles - Materials transfer - Propellants Validate checkout of Servicer stack	Validate transport of Servicer(s) to operational orbit by transfer vehicle(s) Validate transfer of mission control from Space Station Mission Control to Space Station Ground Control. Validate remote demate of TMS Servicer from OTV (as required) Validate remote mating of Servicer with Spacecraft Validate Remote Servicing of Spacecraft, demate and remate of TMS/Servicer with OTV (as required) Validate return of Servicer/ transfer vehicles to Space Station Validate refurbishment/ berthing on Manned Space Station

2.2.4 Maintenance Objectives

For the space station to support the servicing of users payloads it must demonstrate the capability to conduct preventative, corrective, and upgrade maintenance activities on spacecraft systems and the manned space station. The spacecraft systems include both the users payloads and the vehicles based at the space station that regularly support the user missions (TMS, OTV, services, RMS, etc.). The maintenance objective are in Table 2.2.4-1.

2.2.5 Common Servicing Objectives

During this analysis, a few servicing objectives were found to be common to two or three of the servicing tasks. These common objectives are to evaluate remote servicing capabilities, demonstrate manned servicing capabilities, and evaluate semi-automated rendezvous and docking. These objectives are found in Table 2.2.5-1.

Table 2.2.4-1 Servicing Objectives - Maintenance (Module Replacement, Repair/Refurbishment, Decontam

Mission Objective -	Demonstrate Capability To Conduct Preventive, Corrective And Upgrade Maintenance Activities On Manned Space Station And On Spacecraft Systems		
System Objectives	Demonstrate Maintenance Support Equipment At Space Station	Demonstrate Capability of Servicers/Transfer Vehicles	Demonstrate Mai Operations for In Operational
Detailed Objectives	Verify Procedure For rapid replacement of critical failed modules/ components of Space Station elements (corrective) - IVA - EVA (MMU,EMU/Space Crane) Validate TMS/Servicer, Equipment Operations for coorbiting, remote platform Space Station maintenance activities Validate equipment/ Operations for repair/ refurbishment activities on Space Station/Space-craft Validate Maintenance Tools, Work Station, Lighting, Servicing consoles, Communications, Repair Procedures Validate Maintenance Repair/Refurbishment/ Decontamination Processes at Space Station - Solar array laser annealing - Energetic oxygen sputtering	Validate capability of Reuseable Maintenance Servicer(s) - Adequate robotics, telepresence for local, remote operations - Access and removal of failed modules on components - Contamination control and removal - Post mission check-out, refurbishment Validate Capability of TMS Servicer(s) for remote operations Validate OTV/Servicer(s) for Remote Operations	Validate movement of TMS, OTV and Servicer(s) to assembly/stacking position with Space Station RMS Validate mating, standard docking interfaces with TMS/OTV, (other servicers for multiple servicing mission Validate transfer of Maintenance Stack to propellant/materials ports and loading of Stack Validate checkout of Maintenance Stack

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lacement, Repair/Refurbishment, Decontamination)*

entive, Corrective And ed Space Station And		
Capability s/Transfer		Demonstrate Maintenance Operations for Spacecraft In Operational Orbits
pability of aintenance)	Validate movement of TMS, OTV and Servicer(s) to assembly/stacking position with Space Station RMS	Validate Transfer of Maintenance Stack to Spacecraft orbit and rendezvous
robotics, ence for emote ns	Validate mating, standard docking interfaces with TMS/OTV, (other servicers for multiple servicing mission)	Validate transfer of Mission Control to Space Station Ground Control
nd removal d modules nents		Validate remote demate of TMS/Maintenance Servicer from OTV (as required)
ation and removal	Validate transfer of Maintenance Stack to propellant/materials ports, and loading of Stack	
sion check- urbishment		Validate remote mating of Maintenance Servicer with Spacecraft
pability of er(s) for rations	Validate checkout of Maintenance Stack	
V/Servicer(s) Operations		Validate conduct of corrective module of component replacement, refurbishment, decontamination operations
		Validate demate and remate with OTV (as required)
		Validate return to Manned Space Station, refurbishment of servicer/ transfer vehicles and berthing.

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Table 2.2.5-1 Servicing Objectives - Common Servicing Objectives

Mission Objective	Evaluate Remote Servicing Capabilities			Evaluate Semi
System Level Objectives	Demonstrate Ability to Replace Modules	Demonstrate Ability to Transfer Propellants	Demonstrate Ability to Decontamination	Demonstrate O Transfer and
Detailed Objectives	Develop Tools, Aids and Special Test Equipment for Use During Repair/Upgrade Evolutions	Demonstrate Fluids Delivery to Remote Site	Develop Automatic/ Semi-Automatic Contaminant Detection	Demonstrate t aration of S System, Stora Required Flui Materials and
	Demonstrate Remote Rendezvous and Docking with Spacecraft	Provide Fluid Umbilical for Transfer of Required Fluids - Propellants, Pressurants, and Coolants	Validate Contaminant Removal Processes	Demonstrate A Place Servici in Spacecraft
	Demonstrate Access and Removal of Failed or Obsolete Modules	Verify Contamination Avoidance/Control During Transfer Process	Validate Disposal of Contaminants	Verify Rendez Orbit Phasing Spacecraft
	Demonstrate Alignment, Joining/Insertion of Replacement Module (Mechanical, Thermal, Power, Electronics, Instrument)	Confirm Accurate Measurement of Fluid Transfers	Confirm Functioning	
	Verify S/C Functions Following Replacement			

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tives

Evaluate Semi-Automated Rendezvous and Docking			
Demonstrate Ability to Decontamination	Demonstrate Orbit Transfer and Intercept	Demonstrate Convergence on Spacecraft	Demonstrate Link and Unlink Process
Develop Automatic/ Semi-Automatic Contaminant Detection	Demonstrate the Preparation of Servicing System, Storage or Required Fluids, Materials and Modules	Confirm Spacecraft Orientation and Rotation	Demonstrate Docking and Capture Latch Operation
Validate Contaminant Removal Processes	Demonstrate Ability to Place Servicing System in Spacecraft Orbit	Demonstrate Alignment and Rotation Synchronization with Spacecraft	Verify Connection of Communications and Electrical Umbilicals
Validate Disposal of Contaminants	Verify Rendezvous and Orbit Phasing with Spacecraft	Demonstrate Short Distance Approach Using Reference Guides	Demonstrate Electrical and Communications Disconnect
Confirm Functioning			Confirm Latch Release and Undocking Complete

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Table 2.2.5-1 Servicing Objectives - Common Servicing Objectives (Cont)

Mission Objective	Demonstrate Manned Servicing Capabilities			
System Level Objectives	Demonstrate Module Replacement	Demonstrate Fluids Resupply	Demonstrate Spacecraft Manipulation for Mating or Emplacement	Verify Pro Machine I
Detailed Objectives	Demonstrate Module Delivery to Station	Demonstrate Fluids Delivery and Transfer to Space Station	Demonstrate Attachment of Spacecraft or Elements to Manipulators	Demonstrat Function o Aids, Hand Clearances
	Provide Protection and Storage of Modules	Provide Storage Protection, Environmental Control of Fluids: Storable Cryogenic	Demonstrate Berthing/ Storage Clearances, Envelope, Protection	Demonstrat Procedures cations, S Contaminat
	Demonstrate Access/ Removal of Failed Modules	Verify Umbilical/ Fluid Transfer Connections	Demonstrate Spacecraft Assembly, Transfer, Inspection	
	Demonstrate Alignment, Joining, Insertion of Replacement Modules (Mechanical, Thermal, Power, Electronics, Instruments)	Demonstrate Fluid Transfer from Storage to Experiment Module		
	Verify S/C Functions Following Replacement			

g Objectives (Cont)

s		
ids	Demonstrate Spacecraft Manipulation for Mating or Emplacement	Verify Proper Man/ Machine Interfaces
ids ans- ation	Demonstrate Attachment of Spacecraft or Elements to Manipulators	Demonstrate Proper Function of Tools, Aids, Handholds, Clearances, etc
Pro- onmental ids:	Demonstrate Berthing/ Storage Clearances, Envelope, Protection	Demonstrate Operating Procedures, Communications, Safety, Contamination Control
1/	Demonstrate Spacecraft Assembly, Transfer, Inspection	
uid Storage Module		

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2.3 TECHNOLOGY DEVELOPMENT MISSION REQUIREMENTS

2.3.1 Approach

The objective of this section of the study is to present the requirements that satisfy the derived satellite servicing tasks identified for the early space station. The derived tasks were identified in previous sections. These servicing tasks were identified as; space station assembly and modification, large spacecraft assembly on-orbit, resupply of fluids and material, and maintenance, including repair, replacement and decontamination.

Satellite servicing requirements are those elements necessary to perform the servicing tasks to be conducted on the early space station. These requirements were broken down: (1) Satellite Servicing, (2) Large Spacecraft Assembly, (3) Satellite Operations/Support, (4) Future Growth, (5) System Requirements, (6) Subsystem Support, and (7) Space Station Assembly/Operations. These requirements were considered independent of time, cost, benefit and user/space station constraints.

These servicing requirements were derived through evaluation of previous studies performed by NASA, Martin Marietta Corporation, other contractors, the scientific community, and functional analyses conducted with in-house IR&D funds.

2.3.2 Satellite Servicing Integrated Requirements

The satellite servicing system requirements were initially derived from the functional flows identified for each mission objective in section 2.3.3. These functional analyses were conducted with Martin Marietta IR&D funds. Those requirements that were identified from the various functional flows (top level, standard, and unique) were then integrated together, categorized by subsystem, and listed in Table 2.3.2-1. At this stage of the study these integrated requirements do not include physical parameters/characteristics, and were independent of costing, benefit and timeline impacts.

After reviewing the requirements in Table 2.3.2-1, the data base (Appendix B), and NASA requirements; a series of top level requirements for the development of satellite servicing concepts was developed. These were derived independent of cost, benefit, timeline, and physical parameters/characteristics. These requirements were divided into seven major categories (Figure 2.3.2-1): (1) Satellite Servicing Requirements, (2) Large Spacecraft Assembly Requirements, (3) Satellite Operations/Support Requirements, (4) Satellite Servicing Future Growth Requirements, (5) System Requirements, (6) Satellite Servicing Subsystem Support Requirements, and (7) Space Station Assembly/Operation Requirements.

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Table 2.3.2-1 Integrated Facility and Hardware Requirements (Top Level)

Subsystem	Requirements
Structural/ Mechanical	- Servicing Interfaces (TMSs, OTV, Servicers, P/Ls) - Tether Interfaces (P/Ls, EMU) - Mechanisms (Orientation Drives, Deploy/Retract Devices, Release/ Engage Devices) - Transfer Mechanisms (P/Ls, OTV, TMSs, Servicers) - Docking Interfaces (Structural, Utilities/Commoditie Passageway) - Satellites - Berthing Interfaces (STS, TMSs, OTV, Servicers, P/Ls) - Payload Accommodations (Field of View, Support, Alignment/Pointing, Utility/Commodity Interfaces, Servicing)

Electrical	- Electrical Umbilical
	- Power (TBD)
	  - Nominal (ac)
	  - Peak (dc)
	- Battery Charger
	- Tools
	- Solar Array Protective Covers
	- Heaters
	- Transducers
	- General-Purpose Test E
	- P/L in Dormant Mode du

Fluids (Propellants/ Pressurants)	- Space Station
	  - Tanks
	  - Valves, Type & Quantity
	  - Thruster Size, Location and Quantity
	- SS (cont)
	  - Transducers
	  - Status Subsystem
	- TMSs, OTV, Servicers, P/Ls
	  - Tank
	  - Quick Disconnects
	  - Controller
	- TMSs (cont)
	  - Transducers
	  - Valves
	- Propellant Transfer/ Loading Techniques

Environmental	- Cleanliness
	- Structural Attachment
	- Pressure Ventilation (Contamination)
	- Leak Contamination
	- Thermal Control
	  - Radiation Orientation Constraints
	  - P/L Coolant Quick Disconnects
	  - Rotary Fluid Connection
	  - Coolant Pressure and Temperature
	- Thermal (cont)
	  - Valve Open/Close Position
	  - Accumulation Fluid Quantity

Avionics	- Data Processing and Display
	- Data Recording/Storage
	- Commanding
	- Experiment/Payload Management
	- Station Command and Control
	- Umbilical Data Measurement
	  - Propellants/Pressurants
	  - Power
	- Attitude Control
	- Guidance and Navigation
	- TMS/OTV/Satellite Test,
	- Telemetry
	- Life Support Monitoring
	- Antenna/Solar Array Poi

Communication	- Voice Communications (EVA/IVA) - Closed Circuit TV - Navigation (GPS) Data Reception - TDRSS Communication - Standard Communication - Space Station to: SS, OTV, P/Ls, TMS, Servicers - Telepresence

Access	- Access and Clearance for TMS/OTV/TMS/Servicer/P/L Mating/Demating and Deployment/Retrieval
	- Access and Clearance for Either Manned or Remote Checkout
	- Docking/Berthing Clearances
	- Access to Servicing Areas
	  - Thermal Insulation (Accessibility)
	  - Clearance
	- Access and Clearance for Manned/ Remote Servicing
	- Access and Cl Mating/Demati Retrieval
	- Tool and Repl
	- Personnel Acc

Support Services/ Hardware	- Lighting Aids (External/Internal)
	Services
	- Safety
	- Security
	- Photographic
	- Laboratory Analysis
	- Three Dedicated Servicers
	  - Module Changeout
	  - Fluid Replenishment
	  - Contamination Control
	- Two TMSs
	- One OTV
	- Two EMUs
	- Two MMUs
	- Beam Builder(s)
	- Control Consoles
	  - TMS
	  - OTV
	  - Servicers
	  - SS RMS
	Attached and Unattached Missions
	- Alignment Equipme
	  - Mechanical
	  - Optical
	- Basic Checkout Eq Tools

Handling	- SS RMS/Space Crane (Cherry Picker)
	  - Fixed
	  - Mobile
	- Hand Tools
	- Work Stands
	  - Fixed
	  - Mobile
	- Dollies
	- Hangar Extension/Retraction Fixture
	- Portable Hoists
	- Miscellaneous, Handling, Positioning, and Lifting Equipment

Working Space/ Facilities	- Servicing Facilities (External/Internal)
	  - TMSs
	  - OTV
	  Servicers
	  - EMU
	  - MMU
	  - P/Ls
	- Storage Facilities (External/Internal/ Station Keeping)
	  - TMSs
	  - OTV
	  - Servicers
	  - EMU
	  - MMU
	  - P/Ls
	  - Replacement Hardware
	  - Canisters
	- Propellant/Pressurant Storage Facilities
	  - Hydrazine
	  - Cryogenic
	  - Bipropellants
	  - Helium
	  - Nitrogen
	  - Solids
	- Assembly Facilities
	  - External
	  - Internal
	- Construction Facilities
	  - External
	  - Internal
	- Berthing Facilities (Ex Internal)
	  - TMSs
	  - OTV
	  - Servicers
	  - P/Ls

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ments (Top Level)

- Docking Interfaces (Structural, Utilities/Commodities, Passageway)
  - Satellites
- Berthing Interfaces (STS, TMSs, OTV, Servicers, P/Ls)
- Payload Accommodations (Field of View, Support, Alignment/Pointing, Utility/Commodity Interfaces, Servicing)
- Meteoroid Protection
  - Payloads
- Storage, Utilities/Commodities Provisions
- Mating/Demating Mechanisms/Devices

Covers - Heaters - Transducers - General-Purpose Test Equipment - P/L in Dormant Mode during All Servicing Tasks

- TMSs, OTV, Servicers, P/Ls
  - Tank
  - Quick Disconnects
  - Controller
- TMSs (cont)
  - Transducers
  - Valves
- Propellant Transfer/ Loading Techniques
- Servicer
  - Umbilical Robotics
  - Heaters
- Hazardous Vapor Detections
- Solid Propellant Removal Replace Techniques

rol
Orientation Constraints
t Quick Disconnects
id Connection
essure and Temperature
- Thermal (cont)
  - Valve Open/Close Position
  - Accumulation Fluid Quantity
- Stability
- RF Radiation
- Standard Contamination

ation Command and Control bilical Data Measurement Propellants/Pressurants Power titude Control - Guidance and Navigation - TMS/OTV/Satellite Test, Checkout, and Control - Telemetry - Life Support Monitoring - Antenna/Solar Array Pointing
- TDRSS Communication - Standard Communication   - Space Station to: SS, OTV, P/Ls, TMS, Servicers - Telepresence TV Camera

- Docking/Berthing Clearances
- Access to Servicing Areas
  - Thermal Insulation (Accessibility)
  - Clearance
- Access and Clearance for Manned/ Remote Servicing
- Access and Clearance for EVA Mating/Demating and Deployment/ Retrieval
- Tool and Replacement Part Access
- Personnel Access
- Equipment Access
- Work Clearances Translation Clearances

ited Servicers
ngeout
enishment
ion Control
- Two EMUs
- Two MMUs
- Beam Builder(s)
- Control Consoles
  - TMS   - Servicers
  - OTV   - SS RMS
<u>Attached and Unattached Missions</u>
- Alignment Equipment/Tools
  - Mechanical
  - Optical
- Basic Checkout Equipment/ Tools
- Tool Sets
- Dedicated STS Docking Port(s)
- Logistics Support

- Hangar Extension/Retraction Fixture
- Portable Hoists
- Miscellaneous, Handling, Positioning, and Lifting Equipment
- Dedicated Handling Equipment
  - TMSs   - Servicers
  - OTV   - P/Ls

ant/Pressurant Storage Facilities
zine   - Helium
genic   - Nitrogen
pellants   - Solids
y Facilities
nal
nal
- Construction Facilities
  - External
  - Internal
- Berthing Facilities (External/ Internal)
  - TMSs   - Servicers
  - OTV   - P/Ls
- Docking Facilities
  - STS
- Command/Control Facilities
- Laboratory Facilities
- Clean Room Facilities
- Habitable Areas and Resupply Capabilities

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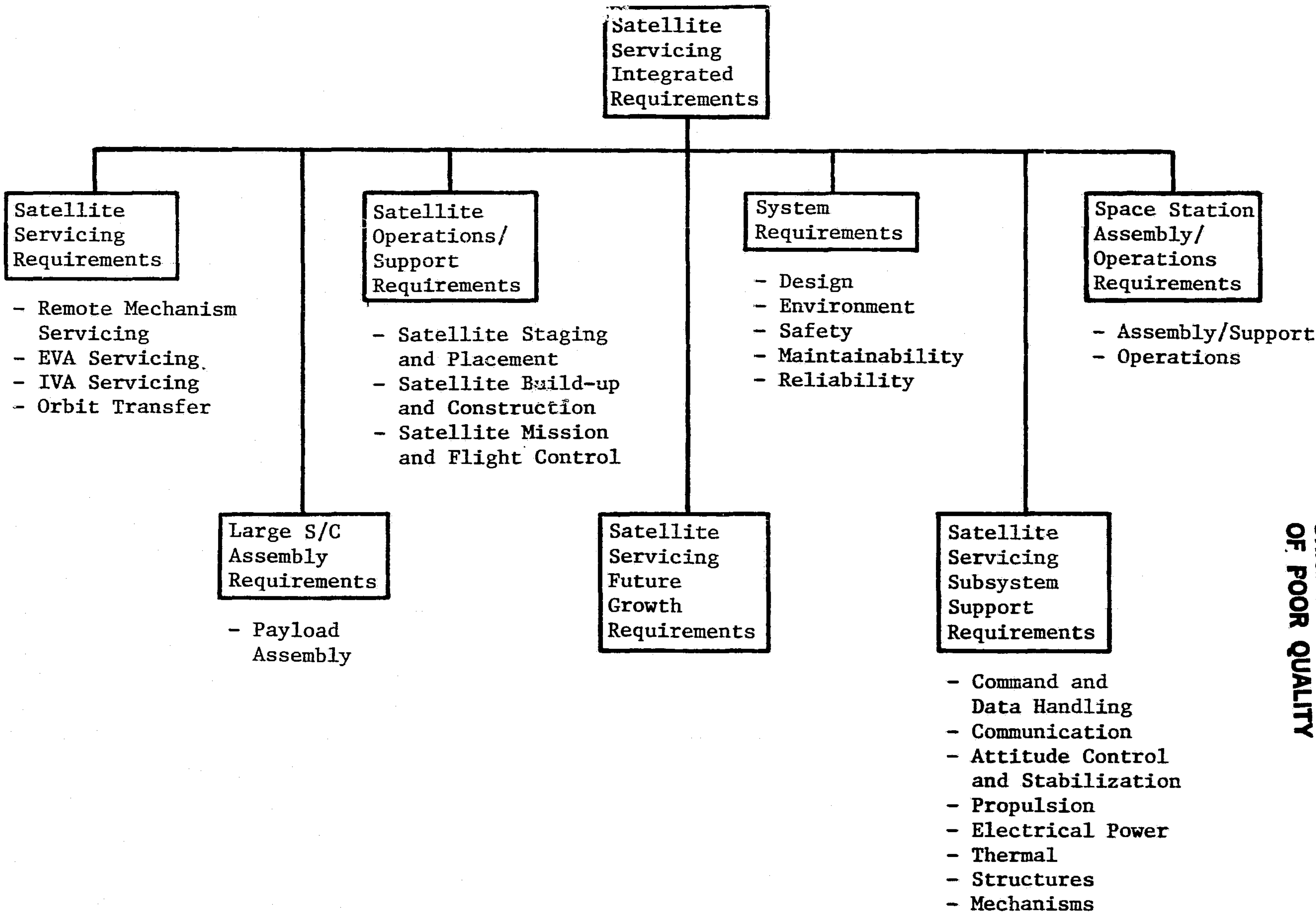

Figure 2.3.2-1 Top-Level System Requirements Breakdown

These requirements were derived under Independent Research and Development (IR&D) funding and are contained in a MMC proprietary document. This document can be delivered upon request.

2.3.3 Functional Analysis

Functional analysis is the means used to identify and analyze the operations required of personnel and equipment to perform a task or a mission within the system requirement constraints. The purpose of this analysis is to analyze and expand the system requirements in sufficient detail such that a system configuration can be developed. This work was also conducted under IR&D funding and is contained in the proprietary document discussed above. This analysis resulted in eighteen scenarios that support a majority of servicing tasks and servicing locations that directly satisfy the mission requirements.

3.0 MISSION DEFINITION

This section includes the design of Technology Development Missions (TDMs), a detailed operations analysis of representative TDMs, and identifies the support equipment required for each TDM. The TDM's were selected as a set of cost effective and time-phased TDM's to demonstrate the wide ranging satellite servicing requirements. An end-to-end operations analysis of the Module(s) Replacement and Fluid Resupply TDM (TDM 7) was conducted and includes man/machine functional allocations, a mission timeline and manpower involvement estimates. Finally, the special support equipment required on the early space station to accommodate the servicing-related needs for this representative TDM has been identified. Basic accommodations needs covering the whole set of TDM's is also included.

3.1 TECHNOLOGY DEVELOPMENT MISSION (TDM) CONCEPTUAL DESIGN

3.1.1 TDM Definition, Scope, and Selection Process

A TDM is a mission designed to demonstrate a specific space station satellite servicing capability or set of capabilities. They are intended to demonstrate and evaluate new technology prototype hardware, operations techniques, and provide proof of concept. This will lead to the desired capability to perform routine satellite servicing activities by the late 1990s. The mission level TDM's will be conducted either at the space station, remote from the space station or a combination of both. Control of each mission will be transferred between the Space Station Mission Control (SSMC) and the Ground Mission Control (GMC) as the individual mission dictates.

Precursor TDM's are defined as those missions or activities necessary to verify or validate system or subsystem elements required prior to the performance of a specific TDM. An example is the validation at the space station of a reusable TMS capable of being refueled and refurbished for follow-on missions.

The purpose of the TDM's identified in section 3.1.2 is to satisfy the mission objectives and requirements discussed in section 2.2 and 2.3. The TDM's have been time-phased based on an orderly evolution of applicable technologies.

Table 3.1.1-1 displays the various satellite servicing scenarios that encompass all the identifiable servicing tasks and locations. The four major tasks have been further broken down into subtasks. Various support and orbit transfer vehicle equipment are specified by the area or location of the servicing task.

Many items were considered during the TDM selection process. Analyses were conducted and discussions were held with knowledgeable NASA and Martin Marietta individuals in the required satellite servicing technology areas. These include:

Table 3.1.1-1 Satellite Servicing Scenarios

	Servicing Tasks	Servicing Locations				
		Space Station	Berthed at SS	S/C In LEO		S/C In HEO
				User S/C	SS Plat	
Assembly	Space Station (Assembly/Modification)	X		X		
	Large Spacecraft	X	X			
Orbit Transfer	Delivery		X	X	X	X
	Retrieval		X	X	X	X
Resupply	Fluids – Earth Storable – Mono, Bi-Prop	X	X	X	X	X
	Fluids – Cryogen	X	X	X	X	X
	Solid Object – Raw Materials	X	X	X	X	X
Maintenance	Module Replacement	X	X	X	X	X
	Refurbishment	X	X	X	X	X
	Decontamination	X	X	X	X	X

- Space station design
- Servicing equipment (TMS, OTV, various servicers)
- Operational procedures for servicing
- Automation techniques (telepresence, robotics, video guidance)
- Fluid transfer (earth storables and cryogens)
- Module replacement
- Contamination (sources, control and decontamination)

In addition to the above technologies, the following items were taken into account while selecting the TDM's;

- Evolution of the early space station (what's available when)
- Current Martin Marietta Space Station Mission Model of planned and potential spacecraft missions (user schedules, servicing requirements/limitations, and operating locations)
- Essential technology demonstrations using a representative progression from the less to more complex tasks
- Space station crew involvement (EVA, IVA, mission control and support activities)

3.1.2 TDM Descriptions

The TDM's described below relate to servicing functions both at or very near to the space station as well as at locations remote from the space station. They represent several levels of technology, programmatic considerations, and various support equipment required in their implementation. Table 3.1.2-1 provides an overall listing of the selected TDM's. It includes the servicing category demonstrated, a description of each TDM, the expected timeframe to conduct the mission, and required precursor TDM's. Orbit transfer capabilities are essential in the majority of TDM's and are added as appropriate for mission completeness in addition to the primary servicing technology intended for each TDM.

In order to demonstrate satellite servicing capabilities on the early space station, various precursor TDMs need to be successfully completed. Figure 3.1.2-1 represents several of the common precursor TDMs. Although equipment is depicted, there are numerous operational procedures that require validation during the precursor phase. Once all the precursor items are available, a mission level TDM can be performed to demonstrate a specific satellite servicing capability.

Figure 3.1.2-2 through 9 display an overall representation of the eight mission level TDM's. Provided for each TDM is a drawing of the satellite along with basic operational information, a figure depicting the servicing activity, an operational/functional flow diagram, and a listing of major operational requirements.

Table 3.1.2-1 Satellite Servicing Technology Development Missions

TMD	Servicing Category	Description	Loc
1	Space Station Assembly, Modification, Resupply, and Maintenance.	Assemble Deployed Energy Section and Initial Crew Habitability Module. Incremental SS Modification, Resupply, and Maintenance.	Spa
2	LEO Transfer, Resupply, and Retrieval (Solid Materials)	Orbit Transfer and Delivery of Materials Processing Free Flyer and Platform. Service Free Flyer and Platform-- Rendezvous/Dock Change Module(s), and Return Processed Material to SS	Rem 28.
		Space Station	
		Free Flyer With Servicer (Single)	
		Materials Processing Platform With Servicer (Multi)	
3	Orbit Transfer (GEO Delivery)	Delivery Far Ultraviolet Spectroscopy Explorer (FUSE) from Space Station to Operational LEO Position	Remo
4	Large Spacecraft Assembly	Assemble Orbiting Very Long Baseline Interferometer (OVLBI) at Space Station and Delivery to LEO	
		Assemble and Check Out	Spac
		Delivery	LEO
5	Resupply (Cryogen)	Resupply Cryogen to Infrared Telescope	Remo
6	Maintenance/ Decontamination (EVA)	Manual Contamination Removal from Gamma Ray Observatory (GRO) after Retrieval from LEO for Servicing at Space Station	Remo
		Space Station Decontamination/ Maintenance	Spac
7	Maintenance/Module(s) Replacement and Resupply (General Purpose Robotic Servicer)	Replace Defective/Obsolete Module(s) and Resupply Fluid for Advanced X-Ray Astrophysics Facility (AXAF) After Retrieval From LEO for Servicing at Space Station Hangar Using General Purpose Servicer	
		Retrieval	LEO
		Service	Spac
8	Resupply (Fluids at GEO)	Resupply Experimental Geostationary Platform (XGP) at GEO Using Space Station TMS/OTV/Fluid Servicer	Remo

lopment Missions

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	Location	Date	Precursors
Energy Section and tability Module. odification, Resupply,	Space Station	1990-1992	TMS Validation from STS
d Delivery of Materi- ee Flyer and Platform. r and Platform-- hange Module(s), and Material to SS	Remote LEO at 28.5°		TMS Operational Validation, Module Servicer Validation
		1991	
h Servicer (Single)		1991	
essing Platform		1993	
er (Multi)			
aviolet Spectroscopy rom Space Station to osition	Remote GEO	1992	OTV Aerobraking Validation
Very Long Baseline VLBI) at Space ery to LEO		1993	OTV Operations Validation, Temporary Spacecraft Element Storage
heck Out	Space Station LEO at 45°		
to Infrared	Remote 28.5°	1993	TMS Operational Validation, Servicer Validation
ion Removal from tory (GRO) after O for Servicing	Remote 28.5°	1991-1993	
ontamination/	Space Station		
/Obsolete Module(s) d for Advanced s Facility (AXAF) rom LEO for Servicing Hangar Using General		1995	TMS Operational Validation, General Purpose Servicer Validation
	LEO at 28.5° Space Station		
ntal Geostationary GEO Using Space luid Servicer	Remote GEO	1996	TMS/OTV Operational Validation, Fluid Servicer Validation

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Purpose: Demonstrate Satellite Servicing Operational Capability on Early Space Station

Precursor TDMs

System & Subsystem Validation Required to Satisfy Mission-Level Objective

Mission Level TDM

Demonstrates a Specific Satellite Servicing Capability or Set of Capabilities - Conducted Either at or Remote from Space Station

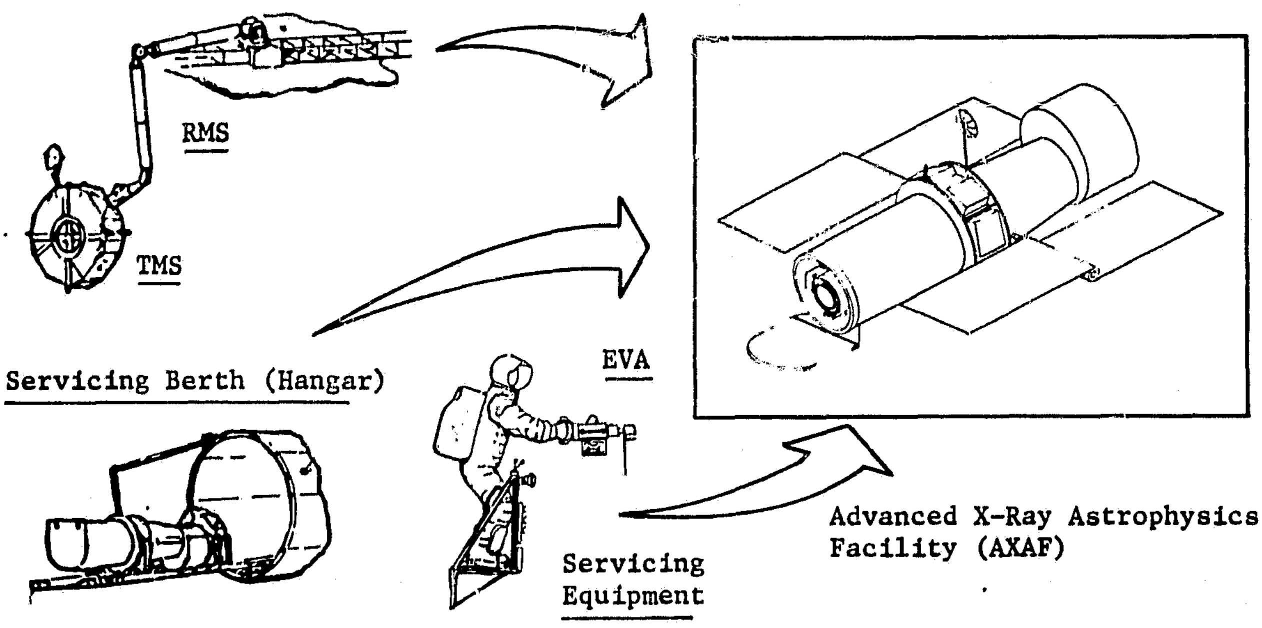

Figure 3.1.2-1 Technology Development Mission (TDM)

TDM 1 demonstrates the assembly of initial sections of the space station, modifications during growth, the resupply of consumables, and the maintenance actions required during the 1990-1992 time frame. The major operational requirements that need to exist to allow the accomplishment of TDM 1 are a STS, TMS, EMU/MMU, a ground and space station crew communications and control network, assembly tools to include CCTV and lighting, alignment equipment, space station RMS, berthing system, environmental controls for man and material, and checkout equipment. The major tasks of TDM 1 include assembly and checkout of the energy section and the initial crew habitability module. The operational scenario is initiated by shuttle delivery, deployment and checkout of the space station energy section. Subsequent shuttle deliveries of space station modules and supplies are then mated or transferred and system level checkouts conducted.

The remaining TDMs share mutually needed operational requirements which must exist to allow the accomplishment of each TDM. They include the shuttle or STS, a space station crane or Remote Manipulator System (RMS), a Extravehicular Mobility Unit (EMU) and Manned Manuevering Unit (MMU), and payload berthing stations with necessary tools and logistic services and support. Most TDMs require the use of a propulsion module and therefore need a Teleoperator Maneuvering System (TMS) or Orbital Transfer Vehicle (OTV), both of which will require a space station control console. Unique propulsion requirements are identified for each TDM.

TDM 2 demonstrates the LEO resupply activity of solid materials to the space station first and later to free flyers and the Materials Processing Platform using the module servicer. The major unique operational requirements that need to exist to allow the accomplishment of TDM 2 are a TMS with ground and SS control interfaces, a ground and space station crew communications and control network, module changeout servicer, docking and undocking mechanism, and a control console for the TMS and servicer. The major tasks of TDM 2 consist of the TMS and module servicer; rendezvous, docking, and changeout procedures. The operational scenario for TDM 2 is initiated by shuttle docking and cargo transfer to the space station. The payload module, module servicer, and TMS are mated, checked out, deployed, and docked with the Materials Processing Platform or a free flyer. Module changeout or processed material recovery, accomplished under ground control, is then conducted and the TMS/servicer is returned to the space station. Processed solid objects are subsequently returned to the earth by the shuttle.

TDM 3 demonstrates the deployment of the Far Ultraviolet Spectroscopy Exployer (FUSE) by incorporating the propulsion unit mating at the space station and the required GEO delivery using an OTV. TDM 3 will first demonstrate the ability of the OTV to function in the space station environment; i.e., hardware, software, and crew interfaces. Second, the capability of the OTV to achieve a GEO delivery with appropriate communications and tracking will also be demonstrated. Lastly, OTV aerobraking will be a precursor in the development of TDM

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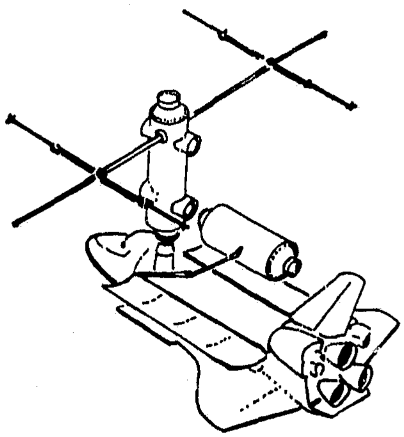
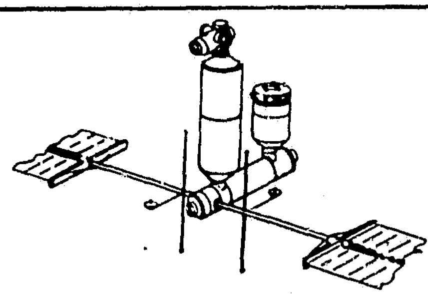
Shuttle Delivery, Deployment, and Checkout of SS Energy Section → Shuttle Delivery of SS Modules and Supplies → Mating of SS Modules and Supply Transfer → System Level Checkouts

Operational Requirements

- STS
- TMS
- EMU/MMU
- Ground/Crew Communications and Control
- Assembly Tools, CCTV, Lighting
- Alignment Equipment
- SS RMS
- Berthing System
- Environmental Control (Man, Materials)
- Checkout Equipment





Title:	Space Station
Inclination:	28.5 deg
Altitude:	460 km/250 nmi
S/C Mission:	Manned Platform--Maintenance Operations and Resupply Base

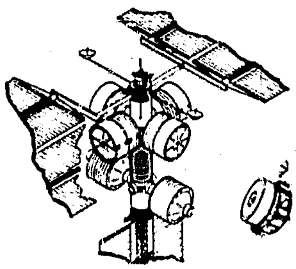
Figure 3.1.2-2 TDM 1 - Space Station Assembly and Modification

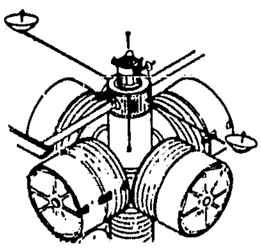
C-2

Shuttle Docking & Cargo Transfer to SS → P/L Module Module Servicer, TMS Mating, and Checkout → P/L Module, Servicer, & TMS Deployment → Module Servicer/TMS Rendezvous & Docking with MMP or F/F → Module Changeout* → Processed Material/Module/TMS Return to SS* → Processed Solid Objects Returned to Earth

Operational Requirements

- STS
- TMS/TMS Control (Ground & SS)
- SS RMS and Control Console
- EMU/MMU
- P/L Berthing Station, Tools, Logistics
- Ground/SS Crew Comm & Control
- Module Changeout Servicer
- Docking/Undocking Mechanism
- Servicer } Console Trade
  TMS } (Single vs Multi)





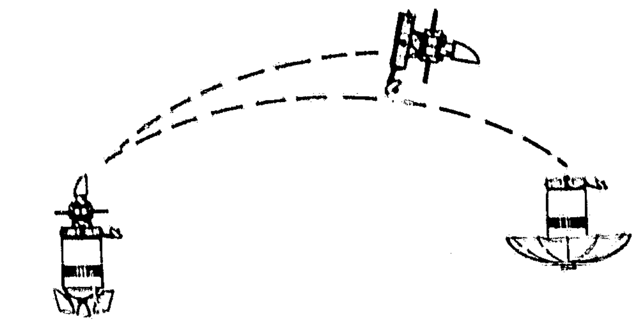
Title:	Materials Processing Plaf\u0254rm (MPP)
Inclination:	28.5 deg
Altitude:	460 km/250 nmi
S/C Mission:	Process Materials Research Experiment

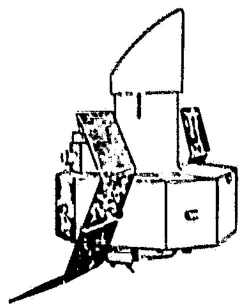
*Ground Control

Figure 3.1.2-3 TDM 2 - Resupply (Materials and Large Module)

Shuttle Docking & FUSE Transfer to SS → FUSE/OTV/(TMS) Mating and Checkout → FUSE/OTV/(TMS) Deployment to Orbit Injection Point

→ Orbit Transfer* → FUSE/OTV/(TMS) Demating and S/C Activation* → OTV/(TMS) Return to SS*





Title	Far Ultraviolet Spectroscopy Explorer (FUSE)
Inclination:	28.5 deg
Altitude:	GEO
Ascending Node between	80 & 120 deg W Long
S/C Mission:	Provides Spectroscopy Data

Operational Requirements

- STS
- Space Crane/RMS
- Crane/RMS Control Console
- EMU/MMU
- P/L Berthing Station, Tools, Logistics
- FUSE Checkout Instrumentation
- TMS
- OTV with Aerobrake
- TMS
  OTV
  Servicer } Console Trade (Single vs Multi)

* Ground Control

Figure 3.1.2-4 TDM 3 - Orbit Transfer (GEO Delivery)

3. The major unique operational requirements that need to exist to allow the accomplishment of TDM 3 are FUSE checkout instrumentation, TMS, OTV with aerobrake, and space station control console(s) for the TMS, OTV, and servicer. The primary mission of FUSE is to perform high and low resolution spectroscopy of stars, galaxies, and intersteller matter in the 90-120 NM spectral region. The operational scenario for TDM 3 is initiated by shuttle docking and payload transfer to the space station. The FUSE spacecraft is mated to an OTV or TMS and a checkout performed prior to deployment. The deployment process is composed of two steps which are delivery to the orbit injection point and orbit transfer. Once positioned in its operational orbit, the FUSE payload is demated from the OTV or TMS and the spacecraft is activated. The OTV or TMS is then returned to the space station. Two years after delivery of the FUSE to its operational orbit, decontamination servicing of the spacecraft is required at the space station. The possibility of a second FUSE mission is also feasible two years after the first mission. During its operational lifetime, servicing of a preventative maintenance nature is forecasted for the FUSE astronomy mission.

TDM 4 demonstrates large spacecraft assembly of the Orbiting Very Long Baseline Interferometer (OVLBI). TDM 4 will demonstrate man's ability to assemble, checkout, and deploy a large spacecraft structure from the Space Station. At this point in time OTV operations will be a proven routine. Facilities will have to be built at the space station to provide adequate storage during the buildup cycle of a large structure. The major unique operational requirements that need to exist to allow the accomplishment of TDM 4 are; OVLBI checkout instrumentation, TMS, OTV with aerobraking, and a space station control console for the TMS and OTV. The primary mission of OVLBI is to perform very long baseline radiometry (1-22 GHZ) using a 50 meter orbiting antenna in conjunction with ground based antennas for high angular resolution observations of galaxies, quasars, pulsars, and superwave remnants. The operational scenario for TDM 4 is initiated by shuttle docking and payload transfer to the space station. The OVLBI payload is then assembled, checked out, and mated and checked out with the propulsion module, OTV or TMS. The two part deployment starts with OVLBI delivery to the orbit transfer point and concludes with orbit transfer. Once positioned in its operational orbit, the OVLBI payload is demated from the OTV or TMS and the spacecraft is activated. The OTV or TMS is then returned to the space station. Eighteen months after delivery of the Orbiting Very Long Baseline Interferometer (OVLBI) the cryogens will require servicing. At approximately two years after operation a failure can be expected which will require additional servicing. Storable propellant for attitude control and stabilization requires servicing every thirty months. This cycle repeats itself throughout the twelve year lifetime of the mission.

TDM 5 demonstrates the resupply of cryogenic coolant fluids to the Infrared Telescope (IRT). TDM 5 requires a LEO delivery using a TMS and servicer combination. Precursors to this mission are the validation of the TMS's operational capabilities and the demonstration

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Shuttle Docking & Cargo Transfer to SS

OVLBI Assembly and Checkout

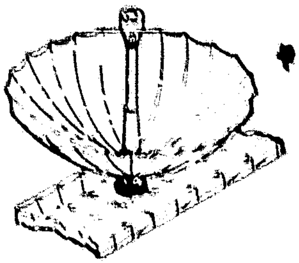
OVLBI/OTV/(TMS) Mating and Checkout

OVLBI/OTV/(TMS) Deployment to Orbit Transfer Point

Orbit Transfer*

OVLBI/OTV/(TMS) Demating and S/C Activation*

OTV/(TMS) Return to SS*



Operational Requirements

- STS
- P/L Berthing Station, Tools, Logistics
- EMU/MMU
- Space Crane/RMS
- Crane/RMS Control Console
- Checkout Instrumentation
- TMS
- OTV with Aerobrake
- TMS } Console Trade
  OTV } (Single vs Multi)

*Ground Control

Title:	Orbiting Very Long Baseline Interferometer (OVLBI)
Inclination:	45 deg
Altitude:	800 km/432 nmi
S/C Mission:	Maps Compact Celestial Radio Sources

Figure 3.1.3-6 DRM 4 - Large Spacecraft Assembly

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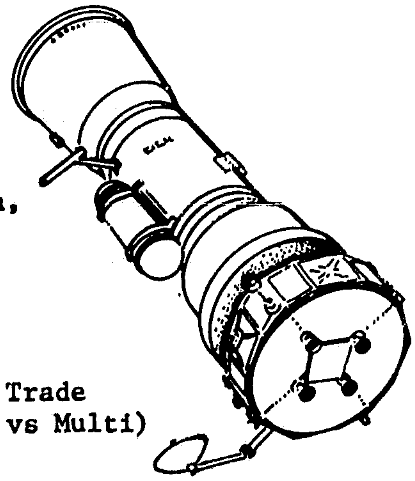
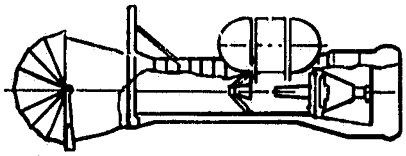
Shutle Docking & Cargo Transfer to SS → Fluids Servicer/ TMS Mating and Checkout → Fluids Servicer/ TMS Deployment and Orbit Transfer * → Fluids Servicer/ TMS Rendezvous & Docking with IRT → Fluid Transfer to IRT* → Fluid Servicer/ TMS Undocking and Return to SS*

Operational Requirements

- STS
- SS RMS and Control Console
- EMU/MMU
- P/L Berthing Station, Tools, Logistics
- Ground/SS Crew Comm & Control
- Fluids Servicer
- TMS
- TMS   Console Trade
- Servicer   (Single vs Multi)
- Docking/Undocking Mechanism

*Ground Control





Title:	Infrared Telescope
Inclination:	28.5 deg
Altitude:	400 km/216 nmi
S/C Mission:	IR Telescope for Photometric, Spectroscopic, and Polarimetric Instruments

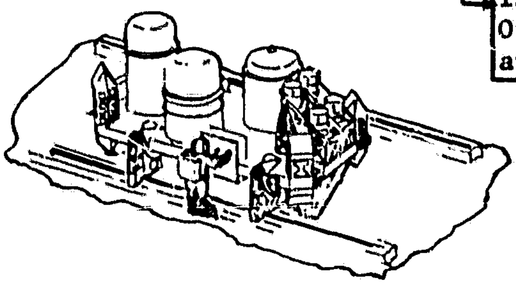
Figure 3.1.2-6 TDM 5 - Resupply (Cryogen)

of remote cryogen transfer capability. TDM 5 will demonstrate the ability of the TMS to perform a remote transfer of cryogens using a fluids servicer in conjunction with the TMS. The major unique operational requirements that need to exist to allow the accomplishment of TDM 5 are a ground and space station crew communication and control network, fluids servicer, TMS and servicer control console mounted within the space station, and a docking/undocking mechanism. The primary mission of the IRT is to perform photometric, spectroscopic and polarimeric observations in the infrared band (2 microns to 1 millimeter), on stars, galaxies, and intersteller matter. The operational scenario of TDM 5 is initiated with cryogenic coolant fluids transfer to the fluids servicer, mating with the TMS, and combined systems are checked out. The servicer and TMS are deployed and perform an orbit transfer in order to rendezvous and dock with the IRT. With the docking complete, the cryogenic coolant fluids are transferred to the spacecraft. Once the transfer is complete, the servicer and TMS undock and are returned to the space station. The refurbishment rate for the IRT is on the order of every 3 to 5 years for instrument and/or a payload changeout. Every eighteen months the cryogens must be serviced. In addition, a retrieval is scheduled every two years at which time the decontamination of the spacecraft can also be accomplished. Mission lifetime is currently scheduled at seven years.

TDM 6 demonstrates the maintenance support and decontamination of the Gamma Ray Observatory (GRO) after it has been retrieved from LEO for servicing at the space station. Concepts that require prior validation include TMS operation, decontamination concept validation at the space station, and servicer validation as applies to the area of decontamination. The major unique operations requirements that need to exist to allow the accomplishment of TDM 6 are a ground and space station communication and control network, decontamination servicing equipment, GRO checkout equipment, and the TMS with a space station control console. The primary mission of the GRO is to perform imaging and spectroscopic measurements of gamma ray background, bursters, quasars, and galaxies over the energy range of 0.03 to 100 MeV. The operational scenario of TDM 6 initiates with the delivery of the decontamination servicing equipment to the space station by the shuttle. The GRO spacecraft is retrieved by the TMS and brought to the space station for general inspection, maintenance, decontamination, and final checkout. Once the servicing is complete, the GRO will be redeployed to its operational orbit by the TMS. The GRO will require maintenance every two to three years to replace/upgrade failed or outdated components and to decontaminate sensors if required. The servicing operation will take place at the space station using remote/automated equipment and/or EVA operations. Upon completion of the servicing task, GRO will be returned to its operational orbit by the TMS.

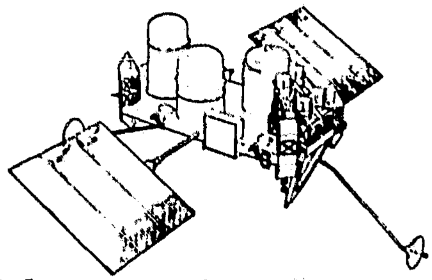
TDM 7 demonstrates the replacement of defective or obsolete module(s) and fluid resupply for the Advanced X-Ray Astrophysics Facility (AXAF). Prior to carrying out this mission, precursor operations such

Shuttle Docking & Servicing Cargo Transfer to SS → Retrieve GRO Using TMS for Servicing at SS → GRO General Inspection, Decon Operation, Servicing, and Checkout → Redeploy GRO to Operational Orbit Using TMS



Operational Requirements

- STS
- SS RMS and Control Console
- EMU/MMU
- P/L Berthing Station, Tools, Logistics
- Ground/SS Crew Comm & Control
- Decontamination Servicing Equipment
- GRO Checkout Instrumentation
- TMS and Control Console



Title:	Gamma Ray Observatory (GRO)
Inclination:	28.5 deg
Altitude:	400 km/250 nmi
S/C Mission:	Studies Energetic Photons

Figure 3.1.2-7 TDM 6 - Maintenance/Decontamination

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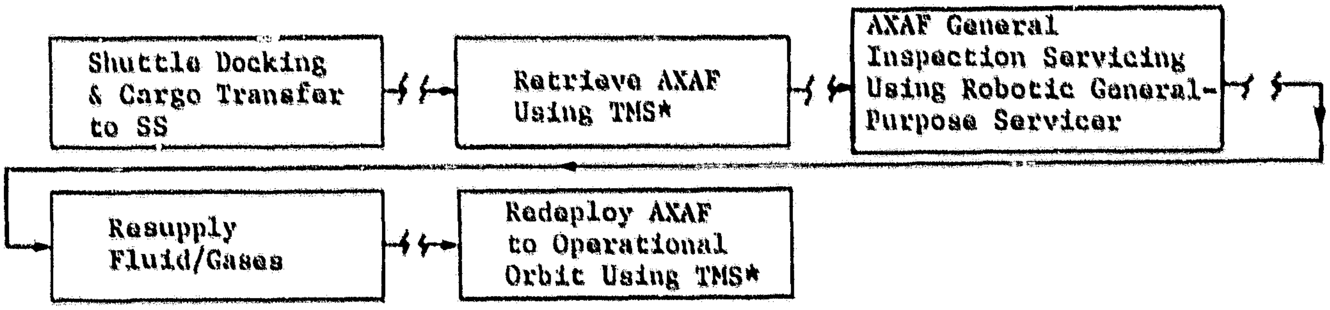
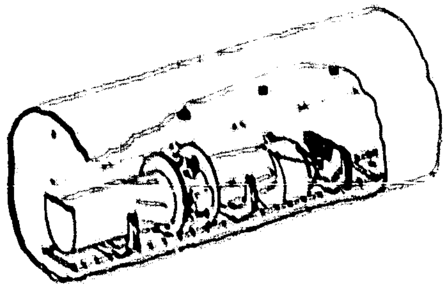
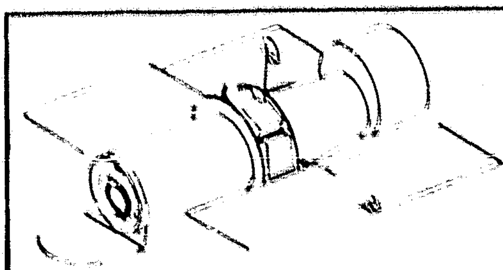






Operational Requirements

- STS
- Space Crane/RMS
- Crane/RMS Control Console
- EMU/MMU
- P/L Berthing Station (Hangar), Tools, Logistics
- Ground/SS Crew Comm & Control
- Robotic General-Purpose Servicer
- AXAF Checkout Instrumentation
- Fluids Servicing Equipment
- TMS, OTV, Servicer } Console Trade (Single vs Multi)

Title:	Advanced X-Ray Astrophysics Facility (AXAF)
Inclination:	28.5 deg
Altitude:	400 km/216 nmi
S/C Mission:	Astrophysics Facility for Determining X-Ray Sources & Physical Properties

*Ground Control

Figure 3.1.2-8 TDM 7 - Maintenance/Module(s) Replacement

as TMS and servicer validation must be demonstrated. The AXAF satellite was chosen to demonstrate the ability to replace modules and resupply gases from a remote/automated general purpose servicer and/or by EVA at the space station. The AXAF will be secured in a non-pressurized hangar after it has been retrieved by the TMS. The hangar will provide micrometeroid protection, thermal control and lighting, work stations, and CCTVs to support the servicing operations. The major unique operational requirements that need to exist to allow the accomplishment of TDM 7 are a space station hangar, a ground and space station communication and control network, robotic general purpose servicer, AXAF checkout instrumentation, fluids servicing equipment, and space station control console(s) for the TMS, OTV, and servicer. The primary mission of the AXAF is to perform high angular resolution imaging and spectroscopy at the X-Ray range (0.1-10 KeV) of x-ray background quasars, galaxies, pulsars, and stars. The operational scenario for TDM 7 is initiated with the delivery by STS of replacement modules and fluids for the AXAF. The spacecraft is retrieved by the TMS and returned to the space station maintenance hangar. The AXAF will undergo a general inspection and servicing using the robotic general purpose servicer and be resupplied with replacement modules, and required fluids and gases. Upon completion of the servicing the AXAF will be redeployed with a TMS to its operational orbit and activated.

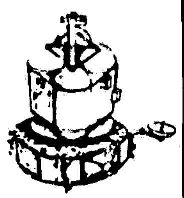
TDM 8 demonstrates the resupplying of fluids at the Experimental Geostationary Platform (XGP) located in a remote geosynchronous orbit. To resupply the expendable fluids on a geosynchronous satellite requires the use of an OTV, a TMS, and a remote/automated general purpose servicer. In order to have continuous control of these vehicles during a mission, space station ground control will be utilized. The major unique operational requirements that need to exist to allow the accomplishment of TDM 8 are a ground and space station crew communication and control network, fluid servicer, TMS, OTV with aerobrake, and a space station control console(s) for the TMS, OTV, and servicer. The primary mission of the XGP is the development and demonstration of a common bus for assembling large antennae platforms at geosynchronous orbit. The XGP will also demonstrate GEO servicing capability. The operational scenario for TDM 8 is initiated with the shuttle delivery to the space station of the required cargo which is transferred to the fluid servicer. The servicer is then mated to the OTV and deployed to the orbit transfer point for the ultimate rendezvous and docking with XGP. Fluid transfer operations will be executed under ground control. Upon completion of servicing activities, the servicer and OTV will then be undocked and returned to the space station.

Figure 3.1.2-2 represents the operational validation of the Technology Development Missions. The TDMs that demonstrate the required space station servicing tasks are shown again here. Each task of the early space station is demonstrated by at least one of the technology development missions. Three of the boxes marked N/A (Orbit transfer retrieval/high energy change (HEC), general maintenance/remote from the space station, and decontamination/remote from the space station) are not considered to be cost effective for early space station servicing.

Shuttle Docking & Cargo Transfer to SS → Fluid Servicer/ TMS/OTV Mating and Checkout → Deployment to Orbit Transfer Point* → Orbit Transfer Rendezvous & Docking with XGP* → Execute Fluid Transfer Operation* → Servicer/TMS/ OTV Return to SS*

Operational Requirements

- STS
- Space Crane/RMS
- Crane/RMS Control Console
- EMU/MMU
- Ground/SS Crew Comm & Control
- Fluid Servicer
- TMS
- OTV with Aerobrake
- TMS } Console Trade
  OTV } (Single vs Multi)
  Servicer



Title

Experimental Geostationary Platform (XGP)

Inclination

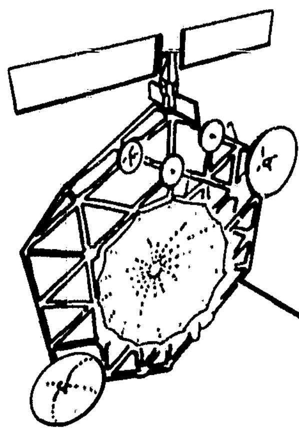
0 deg

Altitude

GEO

S/C Mission

Aggregates Many Missions into a Common Facility



*Ground Control

Figure 3.1.2-9 TOM 8 - Resupply (Fluids at GEO)

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Table 3.1.2-2 TDM Operational Validation

<table>
<tr><th colspan="2" rowspan="3">Task</th><th colspan="3">Location</th></tr>
<tr><th rowspan="2">Space Station</th><th colspan="2">Remote from Space Station</th></tr>
<tr><th>LEC</th><th>HEC</th></tr>
<tr><td rowspan="2">Large Structure Assembly/ Modification</td><td>Space Station Assembly/Maint</td><td>TDM (1)</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Spacecraft Assembly</td><td>TDM (4)</td><td>N/A</td><td>N/A</td></tr>
<tr><td rowspan="2">Orbit Transfer</td><td>Delivery</td><td>N/A</td><td>TDM (2)
4, 5, 6, 7</td><td>TDM (3)
8</td></tr>
<tr><td>Retrieval</td><td>N/A</td><td>TDM (2)
6, 7</td><td>N/A</td></tr>
<tr><td rowspan="3">Resupply</td><td>Fluids Earth Storable</td><td>TDM (1),
2, 3, 4, 5, 6, 7, 8</td><td colspan="2">TDM (8)</td></tr>
<tr><td>Fluids Cryogen</td><td>TDM (1)
3, 4, 5, 7, 8</td><td colspan="2">TDM (5)</td></tr>
<tr><td>Materials, Large Modules</td><td>TDM (1), 2</td><td colspan="2">TDM (2)</td></tr>
<tr><td rowspan="3">Maintenance</td><td>Module Replacement</td><td>TDM (6, 7)</td><td colspan="2">TDM (2)</td></tr>
<tr><td>General Maintenance</td><td>TDM (6, 7)</td><td colspan="2">N/A</td></tr>
<tr><td>Decontamination</td><td>TDM (6)</td><td colspan="2">N/A</td></tr>
</table>

Legend:

( ) First Use of TDM
LEC Low-Energy Change
HEC High-Energy Change

A detailed functional/operational flow diagram of the module replacement and fluid resupply TDM is shown in Figure 3.1.2-10. Operations and necessary equipment are integrated in a sequential ordering of events.

3.1.3 Conclusions

Accomplishment of the selected set of TDM's will demonstrate that the manned space station has the facilities to dock, repair, resupply, assembly or service space systems at or remote from the space station. All the needed support systems will have been exercised. This demonstrated capability will form the basis for follow on, more sophisticated servicing missions, with increasingly more automated functions. Once these servicing capabilities are available, they can be provided to commercial and government satellite systems.

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MODULE(S) REPLACEMENT AND FLUID RESUPPLY OF THE ADVANCED X-RAY ASTROPHYSICS FACILITY

MISSION PLANNING
(GMC & SSMC)*

- Detailed review of module failure/upgrade and fluid resupply requirements
- Obtain and evaluate AXAF design, operations, and test specifications
- Identify required operations (crew, telepresence, robotics) equipment and software
  - Rendezvous operations
  - Docking/separation operations
  - Orbit transfer operations
  - Space station RMS, TMS, EMU, MMU
  - Replacement module(s)
  - Fluids and resupply equipment
  - Servicing tools and aids
  - Contamination control shrouds
  - Servicing berth
- Plan and coordinate mission activities/timelines

RETRIEVAL AND SERVICING PREPARATIONS
(SSMC)

- Prepare/checkout equipments
  - RMS, EMU, MMU
  - Tools, aids, control shrouds
  - Servicing berth
  - Replacement module(s)
  - Fluids and resupply equipment
  - Mission control consoles
- Software (programs and data)
  - Obtain/modify as required
  - Load/verify software
- Walk Through mission timeline noting unique aspects
- Move TMS from storage, checkout and refuel

MODULE(S) REPLACEMENT SERVICING
(SSMC & EVA)

- SSMC assists and monitors: EVA crewman egress using EMU and MMU; CCTV, lighting and RMS
- EVA crewman transits to AXAF with replacement module(s), tools and contamination control shrouds
- EVA crewman puts protective shrouds in place
- EVA crewman uses RMS to: assist with obsolete/failed module(s) removal and storage; assist with new module(s) installation

AXAF SYSTEM CHECKOUT
(SSMC & EVA)

If Checkout Fails

- EVA crewman remains in area to observe and assist in testing as required
- SSMC controls checkout
  - AXAF is powered up
  - Subsystems tested individually and together in operational modes
  - Results monitored and evaluated
  - AXAF placed in safe/inert mode after successful tests
- EVA crewman removes and stores protective shrouds

* GMC
SSMC

Figure 3.1.2-10 TDM 7 Functional/Operation Flow Diagram

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S FACILITY (AXAF)

RETRIEVAL OPERATIONS (SSMC & GMC)

- SSMC moves TMS from berth to orbit boost position using TMS's ACS
- Mission control transferred to GMC; SSMC monitors all activities via ground relay
- GMC controls orbit transfer initiations, phasing, and rendezvous with AXAF using TMS radar
- GMC controls closing of ports susceptible to contamination, retraction of solar panels on AXAF
- GMC controls final alignment and docking activity of TMS to AXAF
- GMC initiates and verifies a safe/inert AXAF status; and conducts orbit transfer of TMS/AXAF to space station vicinity
- Mission control transferred to SSMC

AXAF SATELLITE POSITIONING AND INSPECTION (SSMC)

- SSMC uses RMS to capture AXAF/TMS and berth at servicing port
- Separate and move TMS to storage port
- SSMC controls CCTV and servicing port lighting to perform visual inspection
- SSMC attaches reqired umbilicals (fluid, electrical, control) and verifies AXAF operational status
- SSMC offloads excess AXAF fluids and purges AXAF fluid system
- Mission team (SSMC & GMC) evaluates inspection data and modifies plans (equipment and operations) as required

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FLUID RESUPPLY SERVICING (SSMC)

If Fluid Checkout Fails

- SSMC controls fluid resupply
  - Leak checks performed on connections and AXAF system
  - Input desired fluid quantity
  - Input pressurant gas
  - Purge fluids trapped in connections
  - Disconnect fluid umbilical

REDEPLOYMENT OF AXAF (SSMC & GMC)

- SSMC retrieves, checkout, refuel TMS and docks TMS to AXAF
- SSMC disconnects remaining umbilicals (electrical, control)
- SSMC uses TMS's ACS to move TMS/AXAF from servicing port to orbit reboost position
- SSMC transfers control to GMC
- GMC controls orbit transfer initiation and placement into designated orbit
- GMC controls TMS separation, AXAF power up, port openings, solar panel deployment and remote checkout
- GMC conducts orbit transfer of TMS to space station vicinity and transfers control to SSMC
- SSMC uses RMS to capture and berth TMS at storage port

* GMC - Ground Mission Control
SSMC - Space Station Mission Control

3.2 TDM OPERATIONAL ANALYSIS

A comprehensive end to end operations analysis was performed for each of the conceptual missions identified in section TBD. A function flow was prepared for each TDM and from this a detailed task layout was developed. This task layout was then analyzed to determine the support equipment necessary, manual vs. automated task control and execution, manhours per task and a detailed timeline. This will then aid in developing requirements for satellite servicing TDM's on board the Space Station.

We have accomplished the technology development mission end-to-end operations analysis by analyzing each TDM from a variety of technical viewpoints. We have used substantial satellite servicing mission operations analysis experience from such projects as Skylab integration, Shuttle tile repair, and the MMU/Solar Max repair mission. From these efforts, we have developed a standardized mission planning process we have tailored to the satellite servicing technology development study. This process employs a series of six unique analysis steps, each covering a separate aspect of the mission. Our operations analysis was accomplished by (1) flow-charting the missions to the top and supplement activity levels, (2) defining each operational activity and determining the best method for accomplishing/implementing each, (3) analyzing each activity to determine the appropriate division of manned and automated functions, (4) determining the manpower involvement of flight crew and ground support teams, (5) defining support requirements in terms of hardware, software functions, consumables, and logistic support, and (6) timelining the mission phases and crew activities in sufficient detail to prepare a preliminary operational plan. These will be discussed below relative to TDM #7 to illustrate the above steps. (Steps 1&2, 3&4) have been combined in the discussion below)

3.2.1 Operational Task

The operational tasks listed in Table 3.2.1-1 are the result of steps 1 and 2 described above. The first step involved flow charting the activities as shown in Figure 3.2.1-1. In this functional flow, all the major activities were laid out and then the subtasks were filled in. Through discussion with in-house specialists the best method for implementing these activities was arrived at. In some cases this resulted in task descriptions which vary from that in the functional flow. For this reason, the tasks listed in Table 3.2.1-1 reflect the flavor of the functional flow but do not have a one to one correspondence. Tasks were created from the functional flow through consideration for the equipment involved and the manpower allocation needed. The functional flow was then used as a guide and working document and therefore no effort was spent on updating the the functional flow to reflect the activities realignment which resulted in the Operational Tasks listed.

To further illustrate this process, Figure 3.2.1-1 contains the subactivity "Move TMS from storage, checkout and refuel" under the block "Retrieval & Servicing Preparations". In Table 3.2.1-1 this manifests itself as two tasks, "Move TMS from storage and perform

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Table 3.2.1-1 TDM Operations Analysis-Module Replacement, Retrieval

Operational Task	Control % Man	Control % Auto	Man Hours	Support Equipment	Time, hrs Δ	Time, hrs Timeline	Comment
Prepare/Checkout Equipment, Install AXAF Control Software	80	20	4	SS Hangar, Servicing Area, AXAF Special Equipment	2	-7.0 to -5.0	
Move TMS from Storage and Perform Checkout	25	75	4	TMS Cradle, TMS C/O Umbilicals	2	-5.0 to -3.0	
Move TMS to Resupply Station & Resupply TMS	20	80	2	TMS Cradle, TMS Resupply	2	-3.0 to -1.0	
Move TMS from Resupply Station to Launch Dock	20	80	1/2	TMS Cradle	1/2	-1.0 to -0.5	
Deploy TMS with SS RMS	80	20	1/2	RMS, SS TMS Control	1/2	-0.5 to -0.0	End of Preparation, Beginning of Retrieval
TMS Drift and Orbit Transfer	30	70	3	Ground Control, TDRSS	1	0 to 1	Control of Mission Is Transferred to Ground
TMS Rendezvous and Dock with AXAF	70	30	3	GCS/TDRSS, TMS Control Station	1	1 to 2	
Shut Down Nonessential AXAF Elements; Stow SA, Close Cover, Charge Batt.	50	50	4	GCS/TDRSS, AXAF Control	8	-9 to -1	TMS and AXAF Assumed To Have Independent TM
Inert AXAF Propulsion	90	10	2	GCS/TDRSS AXAF Control	2	-1 to 1	If So Equipped
Verify Docking & Transfer Back to SS	70	30	3	GCS/TDRSS, TMS Control	1	2 to 3	
TMS/AXAF Matches SS Orbit; Capture by SS RMS	30	70	1/2	SS TMS Control, RMS	1	3 to 4	TMS Control Transferred Back to SS

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Table 3.2.1-1 TDM Operations Analysis-Module Replacement, Retrieval (cont)

Operational Task	Control % Man	Control % Auto	Man Hours	Support Equipment	Time, hrs Δ	Time, hrs Timeline	Comment
Perform AXAF Electrical Checkout	30	70	6	AXAF Control & Software	3	16 to 19	Ensure AXAF Has Been Refurbished Properly
Move AXAF to Resupply Station; Perform Leak Check & Resupply	40	60	3	AXAF Cradle, Fluid I/F; AXAF Software & Control	3	19 to 22	Timeline Assumes No Wait for Launch Window
Move TMS to Service Area and Perform TMS Checkout	25	75	4	TMS Cradle, Control and C/O Umbilicals	2	22 to 24	
Move AXAF To Docking Area	30	70	1	AXAF Cradle, Control	1	22 to 23	
Remove AXAF Fluid I/F; Restore Resupply to TMS Config	100	0	2	EMU, AXAF I/F Tools and Equipment	2	24 to 26	If Necessary
Move TMS To Resupply Area, Perform Leak Check and Resupply	20	80	2	TMS Cradle, Resupply Station	2	26 to 28	
Move TMS To Docking Area and Mate with AXAF	20	80	1/2	TMS & AXAF Cradles and Control	1/2	28 to 28.5	
Verify TMS/AXAF Mating	20	80	1	TMS & AXAF Control	1	28.5 to 29.5	End of Servicing
Deploy TMS/AXAF To Launch Position with RMS, Verify RF	20	80	1	RMS, TMS rf & Control	1	29.5 to 30.5	Beginning of Delivery
Release TMS/AXAF, Drift and Orbit Transfer to AXAF Orbit	10	90	3	TMS Ground Control	1	30.5 to 31.5	Transfer TMS Control To Ground Station

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Table 3.2.1-1 TDN Operations Analysis-Module Replacement, Retrieval (cont)

Operational Task	Control %		Man Hours	Support Equipment	Time, hrs		Comment
	Man	Auto			Δ	Timeline	
Move AXAF Cradle into Position on SS Dock Area	50	50	1/2	RMS, AXAF Cradle	1/2	4 to 4.5	
Dock TMS/AXAF into Cradles on SS Docking Area	30	70	1/2	RMS, AXAF and TMS Cradles	1/2	4.5 to 5	End of Retrieval Beginning of Servicing
Separate TMS and AXAF	10	90	1/2	SS TMS Control	1/2	5 to 5.5	
Move TMS to Resupply Area and Offload TMS Propellant	20	80	1/2	TMS Cradle, Resupply Station, TMS Control	1/2	5.5 to 6	Safe TMS and Prepare for Storage
Move TMS to Storage	20	80	1/2	TMS Cradle, TMS Control	1/2	6 to 6.5	
Install AXAF I/F Equip on Resupply Station	100	0	2	EVA, EMU, AXAF I/F Equipment & Tools	2	6 to 8	If Required Due to Nonstandard Fluid I/F
Move AXAF to Resupply Station and Offload Propellant	50	50	1-1/2	AXAF Cradle, SS AXAF Control	1	8 to 9	If AXAF Has An Onboard Propulsion System
Move AXAF into Service Hangar & Connect Umbilicals	30	70	2	AXAF Cradle, Control & Special Umbilicals	1	9 to 10	Electrical Power, Command & Data
Verify AXAF Condition and Refurbishment Needed	10	90	1/2	AXAF Software & Control	1/2	10 to 10.5	Ensure AXAF Condition Is That Planned For
Safe AXAF	0	100	1/2	AXAF Software & Control	1/2	10.5 to 11	Operations To Safe Prior To EVA Service
Perform AXAF Refurbishment Using RMS and EVA Crewmen	80	20	5	AXAF Replacements and Tools, EMU, RMS	5	11 to 16	Using Modules and Replacements Brought By STS Logistics Flight

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Table 3.2.1-1 TDM Operations Analysis-Module Replacement, Retrieval (concl)

Operational Task	Control % Man	Control % Auto	Man Hours	Support Equipment	Time, hrs Δ	Time, hrs Timeline	Comment
Demate TMS and AXAF, Move TMS To Safe Distance	30	70	2	TMS & AXAF GCS/ TDRSS	1	31.5 to	TMS Waits for Positive Checkout
Checkout AXAF ACS, SA Deployment, Pullback Cover	30	70	5	AXAF GCS/TDRSS	2-1/2	32.5 to 35	
TMS Orbit Transfer to SS	20	80	3	TMS GCS/TDRSS	1	35 to 36	
TMS Matches SS Orbit Velocity and Capture By SS RMS	40	60	1/2	RMS SS TMS Control	1/2	36 to 37.5	End of Delivery; TMS Control Transferred To SS TMS Control
RMS Places TMS in Cradle in Docking Area	30	70	1/2	TMS Cradle, RMS TMS Control	1/2	37.5 to 38	
Move TMS To Resupply Station & Offload Propellant	20	80	1 1/2	TMS Cradle & Control Resupply Station	1	38 to 39	
Move TMS To Storage	20	80	1/2	TMS Cradle & Control	1/2	39 to 39.5	
Move AXAF Equipment to Logistics Module for Return to Earth	80	20	4		2	35 to 37	Return AXAF Specific Equipment To Ground for Storage

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MODULE(S) REPLACEMENT AND FLUID RESUPPLY OF THE ADVANCED X-RAY ASTROPHYSICS FACILITY

MISSION PLANNING
(GMC & SSMC)*

- Detailed review of module failure/ upgrade and fluid resupply requirements
- Obtain and evaluate AXAF design, operations, and test specifications
- Identify required operations (crew, telepresence, robotics) equipment and software
  - -Rendezvous operations
  - -Docking/separation operations
  - -Orbit transfer operations
  - -Space station RMS, TMS, EMU, MMU
  - -Replacement module(s)
  - -Fluids and resupply equipment
  - -Servicing tools and aids
  - -Contamination control shrouds
  - -Servicing berth
- Plan and coordinate mission activities/timelines

RETRIEVAL AND SERVICING PREPARATIONS
(SSMC)

- Prepare/checkout equipments
  - -RMS, EMU, MMU
  - -Tools, aids, control shrouds
  - -Servicing berth
  - -Replacement module(s)
  - -Fluids and resupply equipment
  - -Mission control consoles
- Software (programs and data)
  - -Obtain/modify as required
  - -Load/verify software
- Walk Through mission timeline noting unique aspects
- Move TMS from storage, checkout and refuel

MODULE(S) REPLACEMENT SERVICING
(SSMC & EVA)

- SSMC assists and monitors: EVA crewman egress using EMU and MMU; CCTV, lighting and RMS
- EVA crewman transits to AXAF with replacement module(s), tools and contamination control shrouds
- EVA crewman puts protective shrouds in place
- EVA crewman uses RMS to: assist with obsolete/failed module(s) removal and storage; assist with new module(s) installation

AXAF SYSTEM CHECKOUT
(SSMC & EVA)

If Checkout Fails

- EVA crewman remains in area to observe and assist in testing as required
- SSMC controls checkout
  - -AXAF is powered up
  - -Subsystems tested individually and together in operational modes
  - -Results monitored and evaluated
  - -AXAF placed in safe/inert mode after successful tests
- EVA crewman removes and stores protective shrouds

* GMC
SSMC

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Figure 3.2.1-1 TDM 7 Functional/Operation Flow Diagram

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FACILITY (AXAF)

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RETRIEVAL OPERATIONS
(SSMC & GMC)

- SSMC moves TMS from berth to orbit boost position using TMS's ACS
- Mission control transferred to GMC; SSMC monitors all activities via ground relay
- GMC controls orbit transfer initiations, phasing, and rendezvous with AXAF using TMS radar
- GMC controls closing of ports susceptible to contamination, retraction of solar panels on AXAF
- GMC controls final alignment and docking activity of TMS to AXAF
- GMC initiates and verifies a safe/inert AXAF status; and conducts orbit transfer of TMS/AXAF to space station vicinity
- Mission control transferred to SSMC

AXAF SATELLITE POSITIONING AND INSPECTION
(SSMC)

- SSMC uses RMS to capture AXAF/TMS and berth at servicing port
- Separate and move TMS to storage port
- SSMC controls CCTV and servicing port lighting to perform visual inspection
- SSMC attaches reqired umbilicals (fluid, electrical, control) and verifies AXAF operational status
- SSMC offloads excess AXAF fluids and purges AXAF fluid system
- Mission team (SSMC & GMC) evaluates inspection data and modifies plans (equipment and operations) as required

FLUID RESUPPLY SERVICING
(SSMC)

If Fluid Checkout Fails

- SSMC controls fluid resupply
  - -Leak checks performed on connections and AXAF system
  - -Input desired fluid quantity
  - -Input pressurant gas
  - -Purge fluids trapped in connections
  - -Disconnect fluid umbilical

REDEPLOYMENT OF AXAF
(SSMC & GMC)

- SSMC retrieves, checkout, refuel TMS and docks TMS to AXAF
- SSMC disconnects remaining umbilicals (electrical, control)
- SSMC uses TMS's ACS to move TMS/AXAF from servicing port to orbit reboost position
- SSMC transfers control to GMC
- GMC controls orbit transfer initiation and placement into designated orbit
- GMC controls TMS separation, AXAF power up, port openings, solar panel deployment and remote checkout
- GMC conducts orbit transfer of TMS to space station vicinity and transfers control to SSMC
- SSMC uses RMS to capture and berth TMS at storage port

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* GMC - Ground Mission Control
SSMC - Space Station Mission Control

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checkout" and "Move TMS to resupply station and resupply TMS". This is primarily because the two operations will be performed at two different locations and utilize different space station support equipment. Conversely, the entire block "Mission Planning" from Figure 3.2.1-1 is included as a single task "Prepare 1 Checkout Equipment. Install AXAF Control Software" as these are the only activities which will occur on the space station. In a similar manner, each of the subactivities shown in Figure 3.2.1-1 were analyzed to generate the tasks listed in Table 3.2.1-1.

3.2.2 Manpower Allocation

Concurrent with the development of the Operation Tasks was the effort in analyzing the functional flow activities to arrive at the appropriate split between Manual and Automated task execution. This "split" was determined relative to the percentage of the control of the task would be handled by man versus machine (software, control systems etc). For instance, EVA activities would be heavily biased toward manual control, though not necessarily 100% since some intelligent robotics may be used, or the sequence of operations may be software controlled, etc. Likewise, various machine operations will have different degrees of automated control. The desire was to reduce the manual operations as much as possible to free up the crew to perform those operations where the flexability and adaptability of man could be best utilized. For this reason operations which are common to more than one servicing operation were envisioned to have more automated control. Items like the TMS and RMS will have standard functions which will be highly automated because of their broad utility on the space station for a variety of missions. Also used in analyzing the task split was the type of support equipment to be used.

These considerations can be seen when examining Table 3.2.1-1 where the task and equipment could determine the time and crew needed to complete a task as is the case for the task "Deploy TMS with SS RMS". In this case using the RMS to move the TMS from the docking area to a position from which it can released would the 1/2 hour and need one crew member. Certain functions like aligning the end effector to the grapple fixture and moving the RMS from its rest position to the TMS would be preprogrammed since the geometries would be known in advance. (TMS cradle position sensed or known and grapple fixture to cradle would be fixed). These automated "aids" account for the 20% Auto allocated for the task. However, since the bulk of the task will be timed and controlled by the crew member the man is given 80% control. As mentioned earlier, other tasks like the TMS standard routines (checkout, resupply, etc) are envisioned to be highly automated to free the crew since these operations are not unique to this mission but are common to many missions.

3.2.3 Support Equipment

As with the previous section, the support equipment figured heavily in determining the operational tasks in that the methods of accomplishing the tasks is dependent upon the equipment to be used, or vice versa. The equipment listed in Table 3.2.1-1 is primarily space station equipment which will be used by other TDM's and operational missions as

well as TDM #7. The AXAF specific equipment is the software and controller for the AXAF, modules to be replaced and the associated tools. Potential needs are for an AXAF specific cradle, fluid and electrical umbilicals if general purpose space station hardware is not usable instead. All these mission specific equipment needs are assumed to be available on board the SS prior to mission initiation. The cradles are assumed capable of holding the spacecraft so that access is provided for all activities or, at least capable of rotating the S/C to provide access. Ideally, the cradle would also be capable of providing the electrical umbilicals for power, data and command. This has been assumed for the TMS and shows up as a higher percentage of automation for the routine TMS servicing tasks.

The AXAF and TMS control stations are considered to include all displays, software and other necessary control elements to allow a limited number of crew members to effectively control the various tasks to which they are assigned. This implies a high degree of automation which is felt to be necessary for the space station to become cost effective.

The space station service accommodations are assumed to include a docking area, a resupply station where propellant resupply and checkout operations are performed and a hangar area to support the actual servicing operations. The layout is envisioned to be linear with same capability for parallel operations. The TMS could occupy the service hangar while another spacecraft occupied the propellant resupply station, or, the TMS could be moved from storage, be prepared for a mission, and be deploy while another spacecraft were being serviced. This particular TDM does not really demand this flexibility.

3.2.4 Mission Timeline

Having allocated tasks and their manned vs automated division, the man hours and real time for the task can be determined. From this a mission time line can be prepared. These data are shown in Table 3.2.1-1 where Δ is used to denote the real time for the task. In all cases, the manpower referred to is for the space station crew with the exception of mission portions under ground control. (Retrieval and Redeployment). The man hours shown are considered goals for which achieving will enable the mission to become cost effective. As noted in the table, the mission timeline contains no provision for contingencies, so a wait for a launch window prior to redeployment. Also the time plus manpower allocated for actually doing the servicing is only an estimate because the actual servicing tasks are not known. These are however felt to be representative times. Extensive disassembly, or other such time consuming operations are not envisioned because of the costs and complexity associated.

3.3 ACCOMMODATION NEEDS FROM AN EARLY SPACE STATION

3.3.1 Accommodation Needs Task Approach

As presented in the overall study flow diagram, the accommodation needs task utilized the defined TDMs, supporting operational analyses, and definition of servicing tasks generated earlier in the study. These items are the indicated inputs to our task flow diagram shown in Figure 3.3.1-1. With TDM descriptions and the supporting data indicated, we identified completely the required servicing interfaces, and then proceeded to functionally define each physical or operational interface in sufficient detail to drive out the related support equipment required on the Space Station (SS). At a lower level, we found it necessary to examine the TDM servicing mission events profile, and define interface requirements associated with each significant event in the scenario. Although this resulted in the identification of redundant interface needs, it also reduced substantially the possibility of overlooking any important interface.

3.3.2 Early Space Station Capabilities

As a result of Martin Marietta involvement in the recent SS studies, we are particularly sensitive to SS capabilities relative to user needs and the evolving nature of these capabilities. Our recommended evolution plan resulting from those studies is shown in Figure 3.3.2-1, and it specifically shows when certain capabilities are required at the SS. This evolution plan is pertinent to our current satellite servicing study because it shows that some of the major servicing support systems identified from the servicing study are also required for early implementation and growth of the SS. These systems and their recommended implementation dates are indicated in Figure 3.3.2-2, and include the TMS, spacecrane/RMS, hangar, and servicing area facilities. Although not shown on the figure, we strongly recommended implementation of a space maintainable, retrievable OTV in 1992.

All of these systems play a critical role in early SS servicing activities; and each is a complex, costly system requiring technology advancement. It is our belief that these capabilities: (1) are required for SS implementation and operations, (2) will be provided by the SS program, and (3) will be available in a timeframe compatible with satellite servicing TDMs.

3.3.3 TDM Servicing Interfaces

A single TDM was selected for detail interface analysis and support equipment identification. TDM-7, a servicing mission involving the AXAF spacecraft, was selected for the accommodation needs analysis.

The TDM-7 servicing needs are summarized in Figure 3.3.3-1, and include the servicing of MMS modules, focal and non-focal plane instruments, subsystem components and, possibly, the resupply of gases used by the instruments. Such interfaces as those associated with the MMS modules will probably be standardized by the timeframe of TDM-7 (1995), but

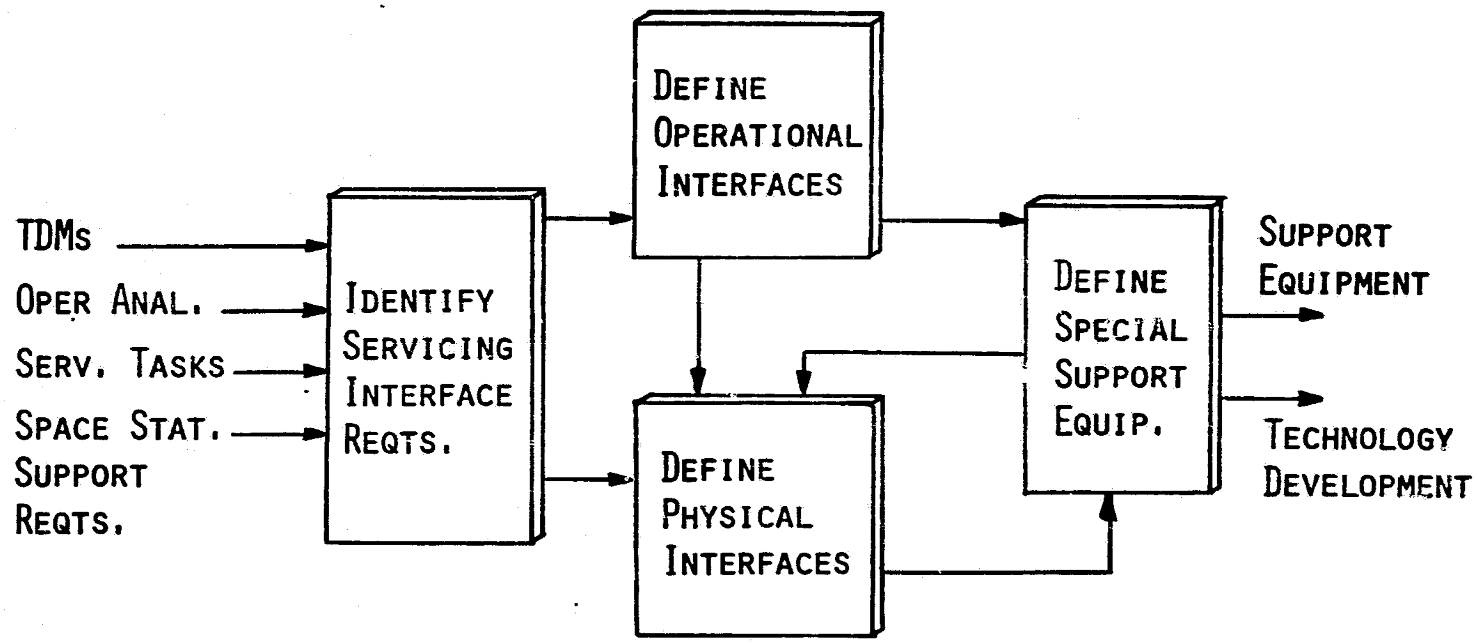

Figure 3.3.1-1 Accommodation Needs Task

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28.5° Space Station

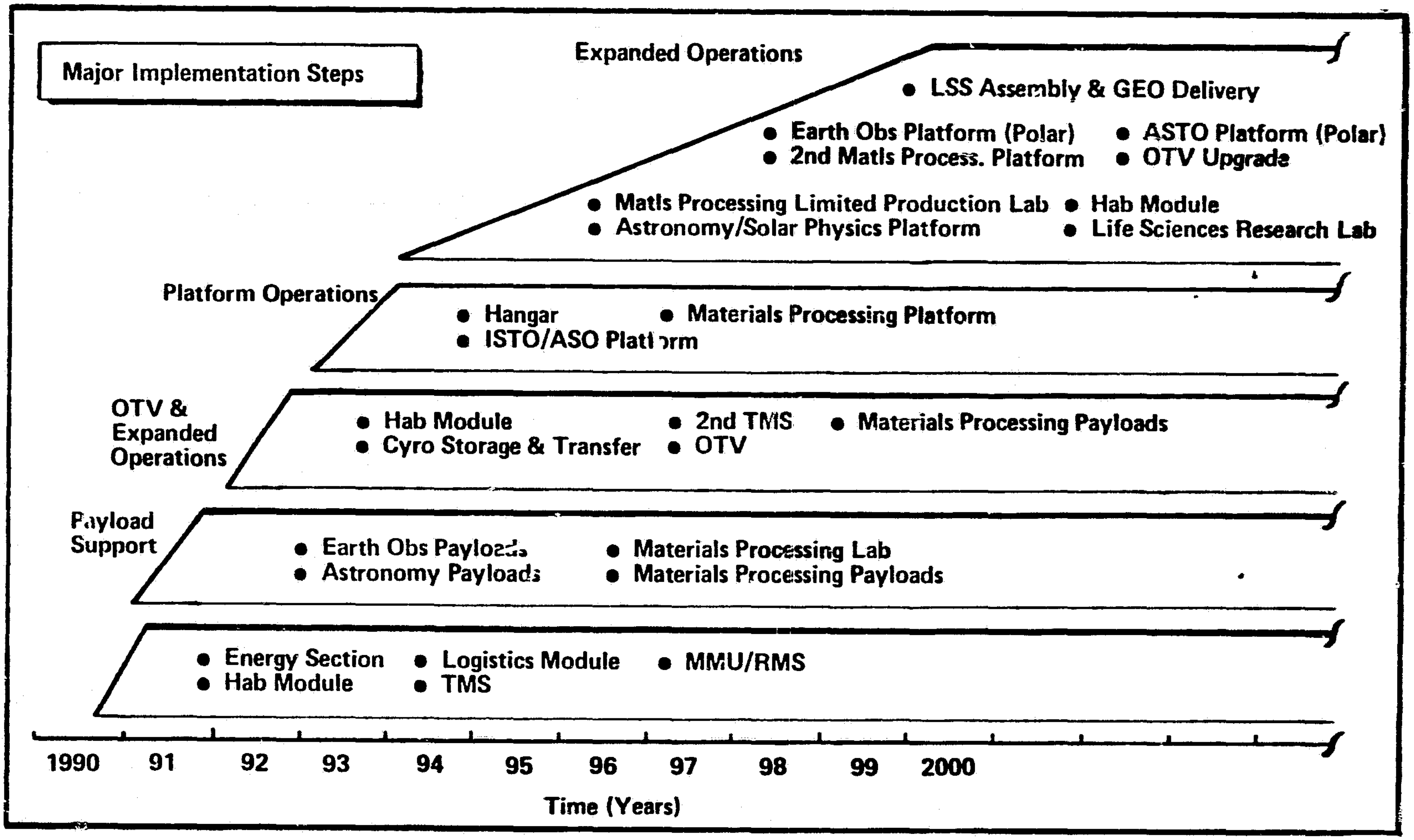

Figure 5.3.2-1 Space Station Evolution Plan

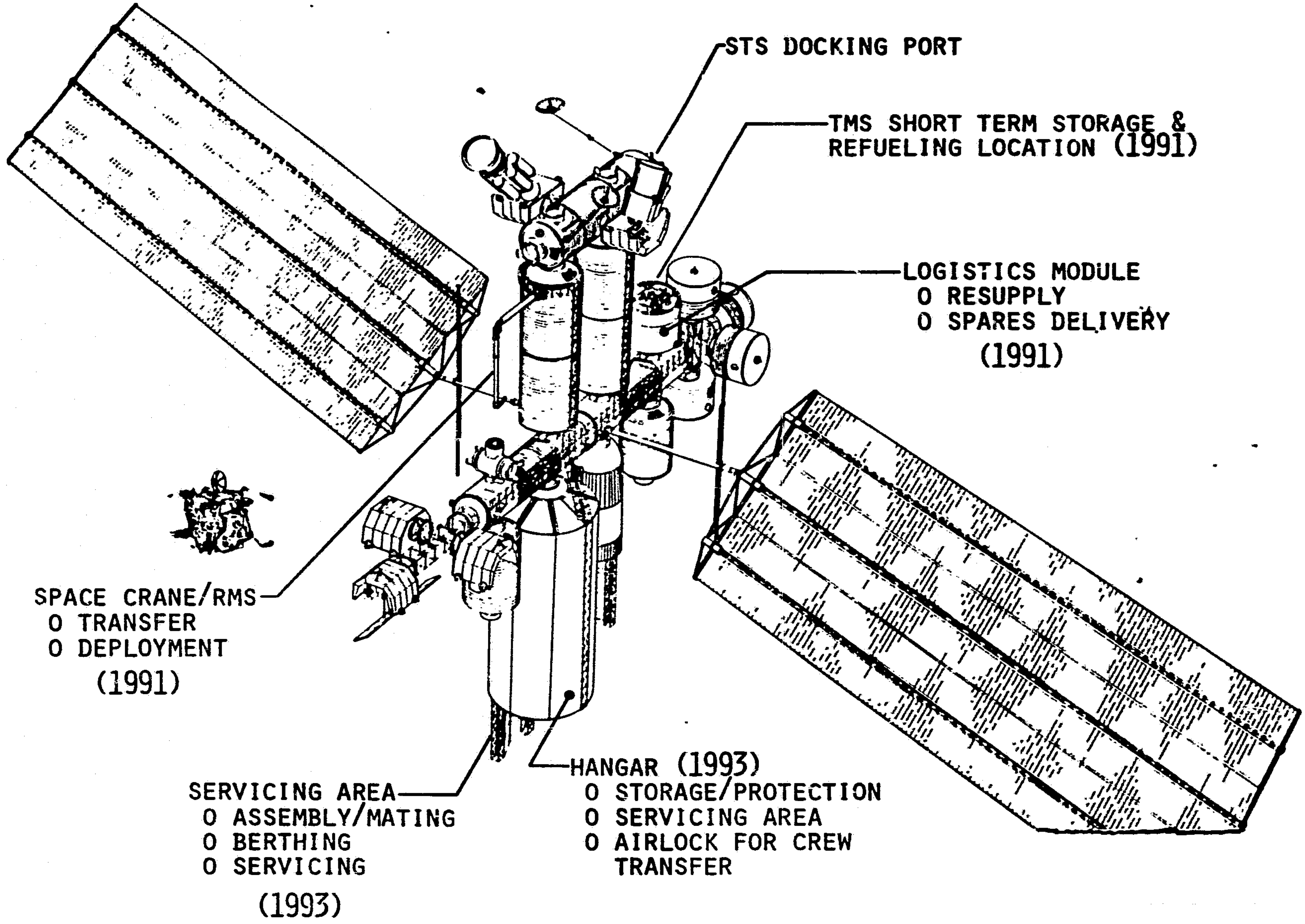

Figure 3.3.2-2 Space Station Servicing Accommodations

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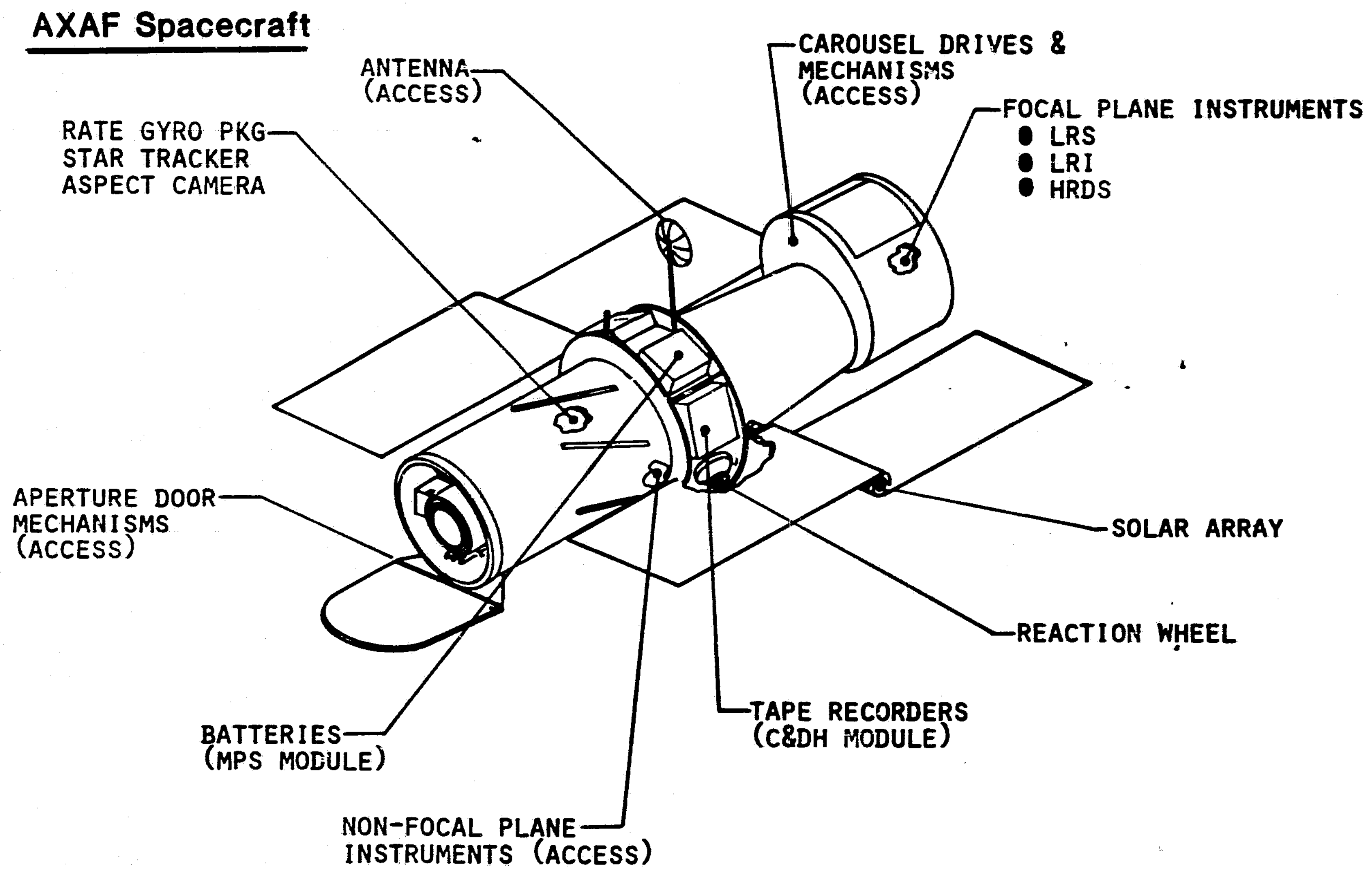

Figure 3.3.3-1 TDM-7 Servicing Requirements

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those associated with the instrumented and subsystem components will not be standardized. Handling of these servicing needs requires maneuverablity along the entire spacecraft and access to several interior sections.

A servicing mission scenario was prepared for accomplishing TDM-7, which involved on orbit retrieval by a TMS, return to the SS, servicing in the SS hangar, and redeployment to the operational orbit. This scenario is defined in Table 3.3.3-1, and was based on the operational analysis performed for TDM-7 and described in section 3.2. The scenario includes preparation activities at the SS prior to AXAF retrieval; TMS deployment, orbit transfer, and AXAF retrieval; inspection, servicing, and checkout at the SS hangar; and redeployment of the spacecraft.

Results of the interface analysis are tabulated in Figure 3.3.3-2 in a format which indentifies needs for certain types of functional interfaces, shown in the left hand column, to support the major activities of the servicing scenario, shown numbered across the top of the figure. The numbered steps relate to the scenario activities presented in Table 3.3.3-1. Need for the Restraint/Stowage functional interface, for example, is indicated by an "X" in a number of the vertical columns. Ths indicates a need for some kind of Restrain/Stowage interface in each of the steps indicated, but it is not necessarily the same Restraint/Stowage interface. As an example, in the preparation activity (step 1) a storage rack or enclosure may be required to restrain or stow a replacement module; while in the berthing activity (step 4), a much more sophisticated mechanism is needed to interface with and restrain the spacecraft during servicing. Similarly, the electrical power interface indicated for step 1 assumes a need to provide sustaining power to a replacement module in stowage; while the power interface required for checkout (step 6) implies provision of power to the spacecraft to activate its systems. The systems interfaces shown exhibit more commonality across the activity steps, and from one TDM to another. The communications Transmit/Receive and Tracking functions shown are those associated with control and monitoring of the TMS as it retrieves and subsequently redeploys the spacecraft. The Video Comm. interface is also related to the TMS activities, and differs from the Video shown under Data Management, which implies use of video systems at the SS to inspect or support spacecraft servicing.

3.3.4 TDM Support Equipment

The interface data summarized in Figure 3.3.3-2 is the basis for identifying related support equipment, or the SS accommodation needs. Some of the complex items such as the TMS, RMS/crane, and hangar were discussed in section 3.3.2, and are assumed to be part of the early SS baseline. THe manner in which some of these systems may be used specifically in support of TDM-7 is illustrated in Figure 3.3.4-1 for steps 2 thru 5 in the servicing scenario. The activities shown include:

Table 3.3.3-1

TDM-7 Servicing Scenario

STEP	ACTIVITY	STEP	ACTIVITY
1	PREPARE EQUIPMENT	9	LEAK CHECK
2	DEPLOY TMS	10	FLUID SERVICING
3	GROUND CONTROL OPERATIONS	11	POST SERVICING CHECKOUT
4	S/C CAPTURE AND BERTH	12	DISCONNECT EQUIPMENT
5	SEPARATE/STOW TMS	13	MATE WITH TMS
6	S/C INSPECTION/CHECKOUT	14	DEPLOY TMS AND S/C
7	CREW PREPARATIONS AND EVA	15	GROUND CONTROL OPERATIONS
8	MODULE SERVICING	16	TMS CAPTURE AND STOW

Interfaces	Servicing Activity Steps 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Structural/Mechanical																
Restraint/Stowage	X	X		X	X		X	X	X	X	X	X	X			X
Handle/Transfer	X	X		X	X		X	X	X	X	X	X	X	X		X
Remove/Replace	X							X								
Miscellaneous	X							X	X	X		X				
Electrical																
Supply Power/Grounding	X					X			X	X	X					X
Covers/Protection	X					X					X	X				
Propellants/Pressurant																
Storage	X								X	X						
Resupply/Replenish	X								X	X						
Thermal Control																
Control/Monitor	X					X				X	X					
Aux TCS						X		X								
Data Management																
Storage						X	X	X	X	X	X					
Processing/Control	X	X				X	X	X	X	X	X					
Video		X		X	X	X	X	X	X	X	X		X	X		X

Figure 3.3.3-2 TDM-7 Interface Definition

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Interfaces	Servicing Activity Steps 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Communications																
Transmit/Receive		X	X	X	X	X					X			X	X	X
Tracking/Control		X		X	X									X		X
Video Comm			X	X										X	X	X
Systems																
Contamination Monitor	X	X		X	X	X	X		X	X	X	X		X		X
Safety	X	X		X	X	X	X	X	X	X	X	X	X	X		X
Lighting/Visibility	X	X		X	X	X	X	X	X	X	X	X	X	X		X
Crew Support							X	X	X	X	X	X				

Figure 3.3.3-2 TDM-7 Interface Definition (Cont.)

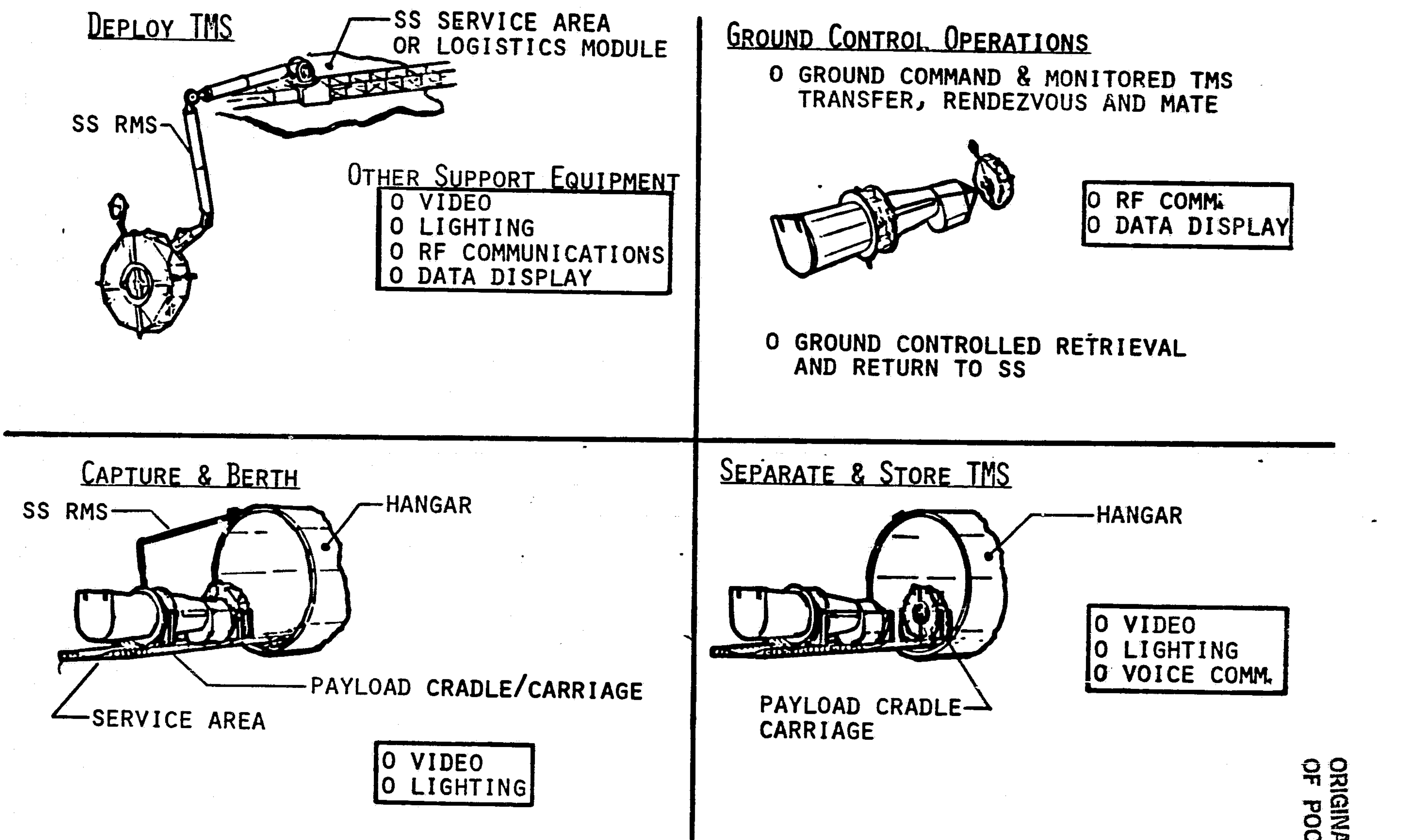

Figure 3.3.4-1 Servicing Activities Evaluation

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a deployment of the TMS by the RMS/crane in preparation for its orbit transfer to the AXAF location,

b control of the TMS via either the space station during RF line-of-sight (LOS) conditions, or by ground control when not within SS LOS is envisioned and will require appropriate communication "handover" procedures,

c berthing of the spacecraft on a payload cradle carriage places it in a workable position for hangar area servicing,

d TMS preparation occurs at this point to free it up for other needs.

The complete list of support equipment required by TDM-7 is presented in Table 3.3.4-1. We have also included our estimation of the technology required to implement each of the equipment items. In most cases, the support equipment requires either current technology or an extension of current state-of-the-art (SOA) which is reasonably expected to occur within the next 4-5 years. We have underlined those items of support equipment on the list that are either unique to TDM-7 or that have not been demonstrated on a prior TDM.

Some of the structural/mechanical equipment items have been illustrated to convey their design characteristics and capabilities. The multiple position translation carriage is shown in Figure 3.3.4-2. The left hand illustration shows how this mechanism will enable a crew person performing EVA servicing, greater flexibility in maneuvering about a spacecraft. The translation carriage permits horizontal translation along the hangar wall, vertical translation, and some adjustment for spacecraft diameter. The left hand illustration shows how an MMS module may be serviced by EVA on an earlier TDM. The right hand illustration suggests use of a general purpose manipulator-servicer attached to the multiple positon translation carriage to perform the same MMS module servicing. Control of the manipulator-servicer can be automated or via telepresence. Since this TDM is a first use for the general purpose manipulator, we have assumed manned control via telepresence.

The payload cradle/carriage is illustrated in Figure 3.3.4-3 (upper left corner). This device is a dual cradle capable of flexible positioning aong the hangar carriage, which, in combination, actually reproduces the STS cargo bay mounting for payloads. Payload diameters of less than 15 feet are accommodated, as in the cargo bay, with unique adapters that provide an interface between the payload and the cradle. Also shown in this figure is a carousel mechanism that attaches to the payload, lifts it from the cradle restraint, and rotates the payload $\pm 90^{\circ}$ to allow greater visibility and servicing accessibility.

Also shown in the right hand side of Figure 3.3.4-3 is a manual approach for replacement of gas-containers. Since one of the AXAF instruments utilizes unusual gases (argon and xenon), it is not recommended that an automated resupply approach be implemented as might be the case for more common propellants or cryogens.

Support Equipment	Development Status A	B	C
Structural/Mechanical:			
Storage for TMS, ORU, Tools, EMU	X		
Space Crane/RMS		X	
Payload Cradle/Carriage	X		
Carousel/Servicing Mechanism	X		
Multiple Position Translation Carriage	X		
EVA Translation Aids	X		
EVA Portable Foot Restraint	X		
Servicing Tools		X	
Tethers, Lanyards, etc	X		
Module Service Tools (MMS)	X		
General Purpose Robotics Servicer		X	
Electrical:			
Power Supply and Control	X		
Umbilical Connection		X	
Protective Covers	X		

A - Current Technology
B - Extension of Current State-of-the-Art (SoA)
C - New Technology Development

Table 3.4-1

TDM-7 Support Equipment (Cont.)

Support Equipment	Development Status A	B	C
Data Management:			
Data Processing and Control	X		
Storage		X	
Software	X		
Displays/Keyboard	X		
Communications:			
RF Sets (TMS and EVA)	X		
Rendezvous Radar (TMS)		X	
Rendezvous Radar (SS)			X
Serv Antenna Hat/Umbilical	X		
Propellant Rdsupply:			
Storage for Gases and Fluids		X	
Pressurant Transfer		X	
Fluid Transfer			X
Vent/Containment Hardware		X	
Systems:			
Contamination Monitors		X	
Lighting	X		
Safety Equipment		X	
EMU/Resupply		X	
Serv Procedures		X	

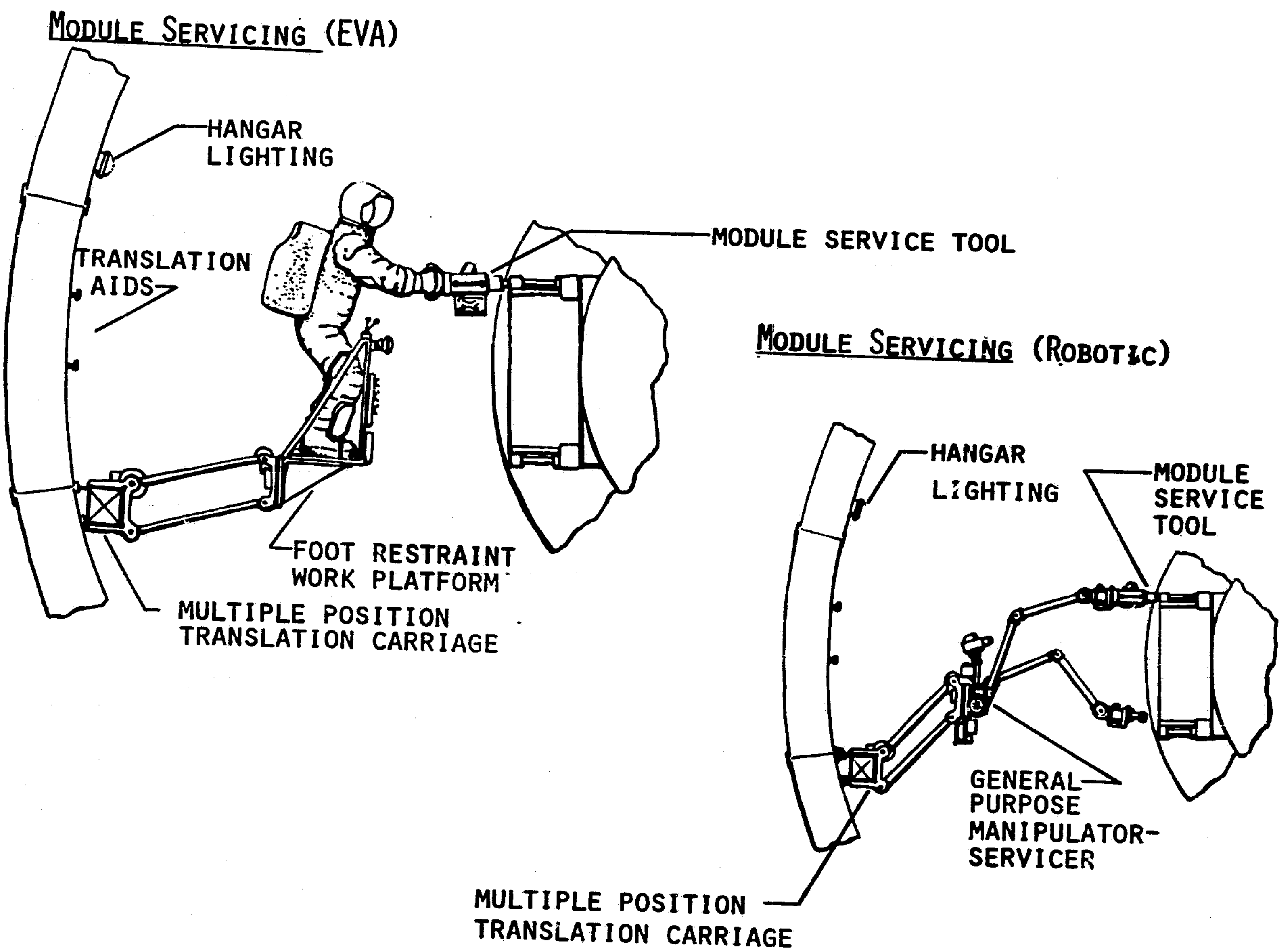

Figure 3.3.4-2 Servicing Activities Equipment

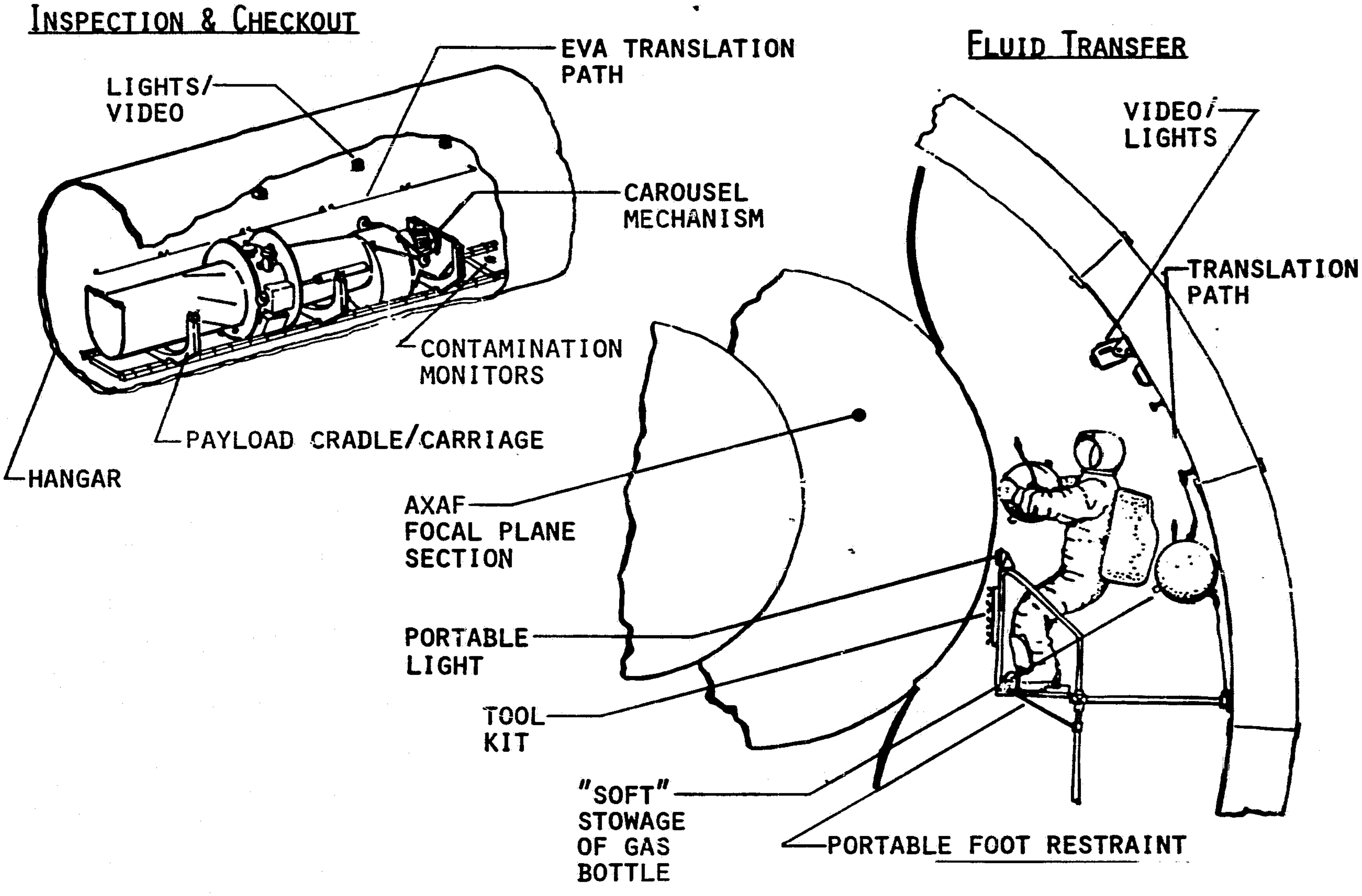

Figure 3.3.4-2 Servicing Activities Equipment (Cont.)

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3.3.4.1 Support Equipment Commonality

The detail analysis of support equipment needs performed for TDM-7 could not be completed for all the other TDMs. However, a relatively high level evaluation of support equipment needs for the other seven TDMs reveals several areas of potential equipment commonality with the needs of TDM-7. These commonality trends can be seen in Figure 3.3.4.1-1. The TDM-7 support equipment is listed in the left hand column, and an 'X' in another of the vertical columns indicates potential commonality between the TDM-7 equipment and the other TDM.

Some examples of this commonality are presented to further explain the data included in Figure 3.3.4-4.

a. The storage provisions equipment can be designed flexibly to accommodate the needs of multiple missions.

b. Such items as the RMS and TMS are applicable to most, if not all, missions serviced at the space station.

c. The payload cradle, as indicated previously, is designed flexibly enough to accommodate any payload compatible with cargo bay mounting. For smaller diameter payloads (less than 15' diameter) such as FUSE suggested for TDM-3, adapters can be identified as unique mission equipment which will interface with the payload cradle.

d. The general purpose robotics servicer appears to be applicable for TDMs-2, 5, and 8, which are all remote applications. The general purpose robotics servicer was proposed for TDM-7 to demonstrate its capacity for remote servicing operation such as these suggested TDMs. However, it will probably be necessary to provide unique end effectors for each of these TDMs.

e. Umbilical connection appears to be a candidate for commonality which also may require a unique connector interface.

f. The RF sets and radar apply to RF control of the TMS for the location of remote payloads, and are common to the TDMs indicated.

g. Proper design of the data processing and control capability at the space station should provide a flexible enough capability to accommodate most payloads serviced at the space station.

3.3.5 Servicing Issues and Trades

In performing the accommodations analyses described in this section, a number of servicing related issues and trade studies were identified, which could not be addressed in this study effort. These issues and trades are identified in Table 3.3.5-1, together with some comments on optional approaches and implications.

TDM 7 SUPPORT EQUIPMENT	TDM 1 SS ASSY	TDM 2 RESUPPLY	TDM 3 GEO XFER	TDM 4 LSS ASSY	TDM 5 RESUPPLY CRYO	TDM 6 REFURB	TDM 8 RESUPPLY GEO
• STORAGE PROVISIONS		X	X	X	X	X	X
• SS RMS		X	X	X	X	X	X
• PAYLOAD CRADLE		X	X*	X		X	
• CAROUSEL MECHANISM						X*	
• ROBOTICS SERVICER		X*REMOTE			X*REMOTE		X*REMOTE
• UNIVERSAL SERVICE TOOL						X	
• SS TOOL KIT	X			X		X	
• EVA TRANSLATION	X	X		X		X*	
• EVA RESTRAINT	X	X		X*		X	
• TETHERS/LANDYARDS	X	X		X		X	
• POWER SUPPLY/ CONTROLS			X*	X*		X*	
• UMBILICAL CONNECTION			X*	X*		X*	
• PROTECTIVE COVERS ELECT/OTHER						X*	
• RF SETS		X	X	X	X	X	X
• RADAR		X	X	X	X	X	X

Figure 3.3.4.1-1 Support Equipment Commonality

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TDM 7 Support Equipment	TDM 1 SS Assy	TDM 2 Resupply	TDM 3 Geo Xfer	TDM 4 LSS Assy	TDM 5 Resupply Cryo	TDM 6 Refurb	TDM 8 Resupply Geo
• Ant/Cable Coupler				X*		X*	
• Data Display				X	X	X	X
• Data Storage				X		X	
• Data Proc/Control		X		X	X	X	X
• Video		X	X	X	X	X	X
• Software			X*	X*	X	X*	X
• Contam Monitor			X			X	
• Lighting		X	X	X*	X	X*	X
• Safety Eq/Proc		X		X	X	X	X
• Gas Storage					X*		X*
• Fluid Storage					X*		X*
• Pressurant Xfer					X*		X*
• Fluid Transfer					X*		X*
• Vent Equipment					X*		X*
• EMU Resupplies		X		X		X	
• Service Procedures		X*	X*	X*	X*	X*	

*Potential Unique Equipment/Software Required or Adapters Needed

Figure 3.3.4.1-1 Support Equipment Commonality (cont)

Table 3.3.5-1

Servicing Issues & Trades

ISSUE	OPTIONS/COMMENTS
UMBILICAL ATTACHMENT	- MECHANIZED APPROACH REQUIRES STANDARD S/C DESIGN - OPTIONS INCLUDE EVA OR ROBOTICS ATTACHMENT - RF ANTENNA HAT/PLACEMENT IS S/C UNIQUE
CENTRALIZED VS DISTRIBUTED PROPELLANT/PRESSURANT RESUPPLY	- CONTAINER (FLUID/GAS) CHANGEOUT OR PROPELLANT/ PRESSURANT RESUPPLY - DISTRIBUTED PLUMBING FROM CENTRAL SOURCE, OR STORAGE/ TRANSFER CAPABILITY IN SERVICING AREA
PAYLOAD CRADLE AND CARRIAGE VS SERVICING CAROUSEL	- CRADLE/CARRIAGE TAILORED TO STS BAY INTERFACE (SIMPLE/FLEXIBLE) - LIMITED ACCESS WITHOUT 180° ROTATION - CAROUSEL ENHANCES ACCESS FOR MAN OR MACHINE - MORE COMPLEX DESIGN FOR STANDARD INTERFACE
DEDICATED VS MULTIPURPOSE SERVICER	- DESIGN COMPLEXITY OF MULTIPURPOSE (FLUIDS, GASES, MODULES, MISC) SERVICER - FEASIBILITY OF IMPLEMENTING MULTIPLE, STANDARD S/C INTERFACES CONCURRENTLY
EVA VS GENERAL PURPOSE SERVICER	- GENERAL PURPOSE SERVICER IMPLIES FLEXIBLE DESIGN AND STANDARD S/C INTERFACES - SERVICER CHECKOUT AT SS BEFORE IN SITU OPERATIONS - S/C ACCESSIBILITY MAY REQUIRE EVA

Table 3.3.5-1

Servicing Issues & Trades (Cont.)

ISSUE	OPTIONS/COMMENTS
SS PAYLOAD CHECKOUT VS GROUND CHECKOUT	- GROUND POCC HAS BEST CAPABILITY FOR PAYLOAD CHECKOUT AND DIAGNOSIS - SS CHECKOUT REQUIRES PAYLOAD UNIQUE INTERFACE/SOFTWARE/PROCEDURES - SOME SS CHECKOUT MAY BE NECESSARY
GROUND VS SS CONTROL OF TMS	- SS NORMALLY CONTROLS TMS DURING LOS - SCHEDULED SERVICING PLANNED DURING CLOSE ORBITAL PROXIMITY - EMERGENCY SITUATION MAY REQUIRE OVER-THE-HORIZON RETRIEVAL WITH GROUND CONTROL OF TMS

4.0 Programmatic Analysis

The major tasks accomplished as part of our satellite servicing programmatic analyses are (1) space station capability evolution (2) satellite servicing economic benefits (3) critical items (4) precursor technology schedules (5) technology demonstration mission schedules, and (6) technology demonstration mission associated costs. We have used programmatic data generated in our parallel Space Station Needs, Attributes, and Architectural Options study to guide our technology development mission (TDM) development and phasing. The space station evolution plan identifies the time period when required interface capabilities would be available for satellite servicing tasks. The TDMs were prioritized in a time-phased sequence based on the economic benefits analysis conducted for space station.

The critical items identified were hardware and technology issues that have an impact on satellite servicing done at or by a space station system. Schedules for critical precursor technologies have been prepared to determine the critical paths and span times of the critical items. In addition, we have prepared an overall schedule for accomplishing the TDMs.

We have estimated the cost associated with performing TDM 7 which includes maintenance/module replacement and fluid resupply of the Advanced X-Ray Astrophysics Facility (AXAF) using a general purpose robotic servicer at the space station.

4.1 PLANS AND SCHEDULES

To establish compatibility between our proposed TDMs and the time-phasing of planned space station capability we have referred to the major implementation steps of our space station evolution plan (Figure 4.1-1). We selected real missions in developing our conceptual TDMs so that technology objectives would be accomplished at lowest cost and maximum benefit to the satellite service users. In selecting real missions, two important issues were considered. First, affordability of the missions within the time period of interest was considered. And second, we compared the desired servicing operational demonstration accommodation requirements with the space station evolution plan to check for compatibility with hardware availability in the time frame desired.

To prioritize accomplishment of TDM objectives we determined those satellite servicing capabilities with the largest economic payoff as is shown in Figure 4.1-2. We chose to schedule those TDMs with the highest payoff as early as possible during the evolution of the space station. We plan to emphasize the demonstration of GEO delivery capability because of its high, positive benefit to cost ratio. By contrast, we have not attempted to demonstrate GEO servicing early because of its low demand and its low benefit to cost ratio.

The time phasing of satellite servicing tasks is shown graphically in Figure 4.1-3. This figure indicates the quantity and percentage of each of the various types of servicing opportunities from 1991-2000. The time phasing of these satellite servicing tasks provide several insights on servicing demand. First, orbit transfer requirements (delivery and retrieval) are shown to be primary tasks during the early space station era. This task requirement is shown to drop off in the later period, primarily because of the inability to project missions that far into the future. In reality, orbit transfer demand is expected to remain high into the late 1990s. Second, resupply requirements are also significant in the early years and are projected to increase generally throughout the period. Third, we project satellite maintenance activities (repair, refurbishment and decontamination) to remain high.

To meet the scheduled satellite servicing TDMs, we identified and evaluated a number of critical items. We considered the following four categories in determining critical items; (1) high economic payoff potential, (2) technical risk, (3) long development spans, and (4) critical path items. As is shown in Table 4.1-1, a space based, aerobraked OTV fell into all four of these categories and is probably most critical to achieving the economic benefits of performing satellite servicing from a space station. Other items that would follow closely in criticality would be a space based TMS vehicle and a rendezvous and docking system which will enable us to perform satellite servicing remote from the space station or to return the satellites for maintenance and repair at the space station. In addition, we feel that a spacecraft standardization program to establish on orbit maintenance requirements is an important and critical item related to satellite servicing.

To develop these critical items in a timely manner the critical precursor technology schedules identified in Figure 4.1-4 will need to be met. These schedules correspond to the technology evolution plan presented earlier and show the results of our analysis of current, planned, or recommended technology development effort. These schedules indicate the approximate schedule spans for ground development (solid bars), shuttle development flights (shaded bars), and space station development missions (clear bars). In addition, we have indicated the approximate dates of flight tests and initial operational capability (IOC) of each capability. These schedules have helped us to identify critical items and to plan TDMs.

The schedule in Figure 4.1-5 shows the order and span times for the selected TDMs. The span times for TDMs 1 and 2 represent the period of time during which a set of missions would be performed to accomplish all desired objectives of each particular TDM. The span times for TDMs 6 and 7 are somewhat uncertain because the actual time for satellite maintenance and module replacement would be dependent on the satellites selected for those TDMs.

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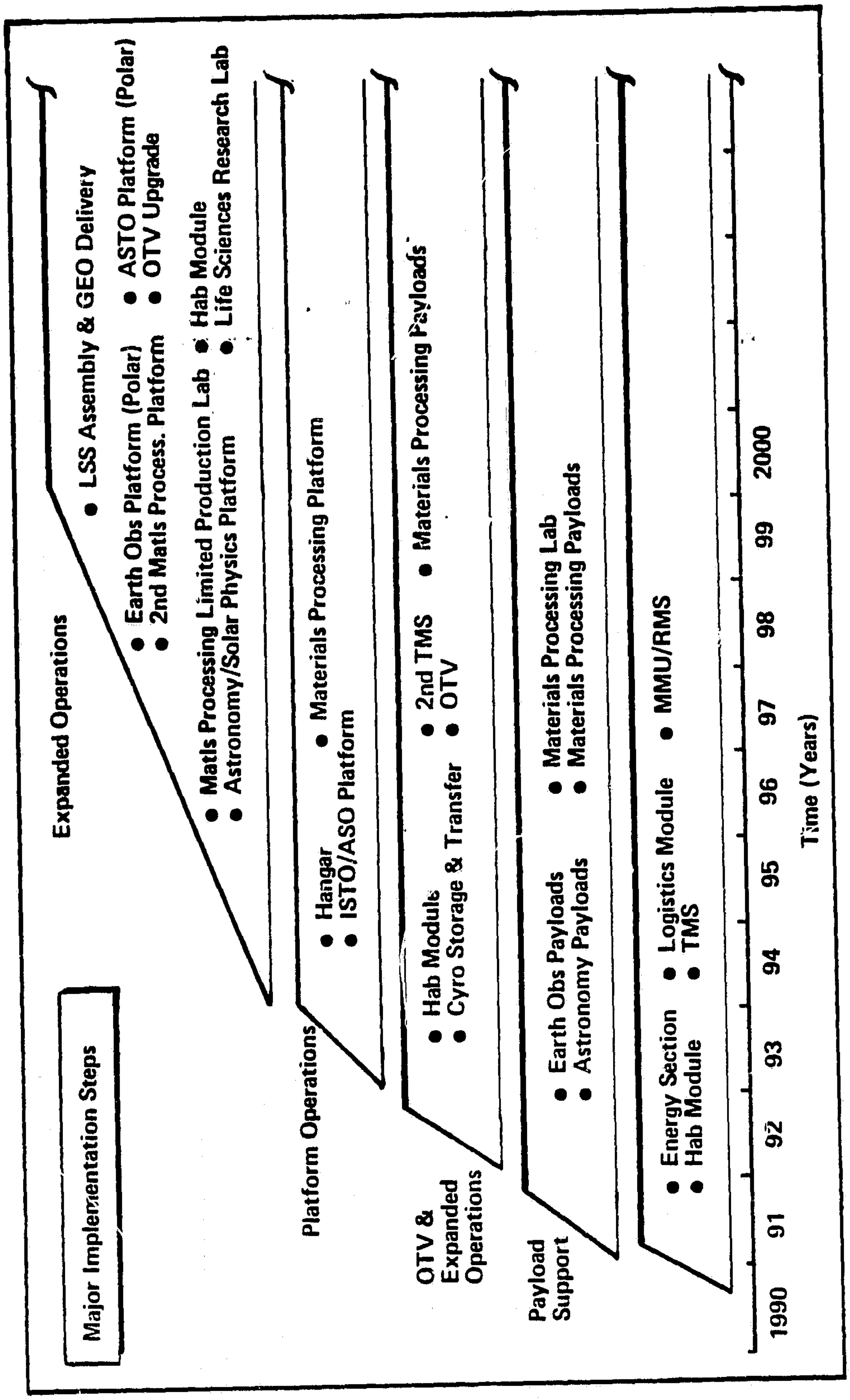

Figure 4.1-1 Recommended Evolution Plan 28.5° Space Station

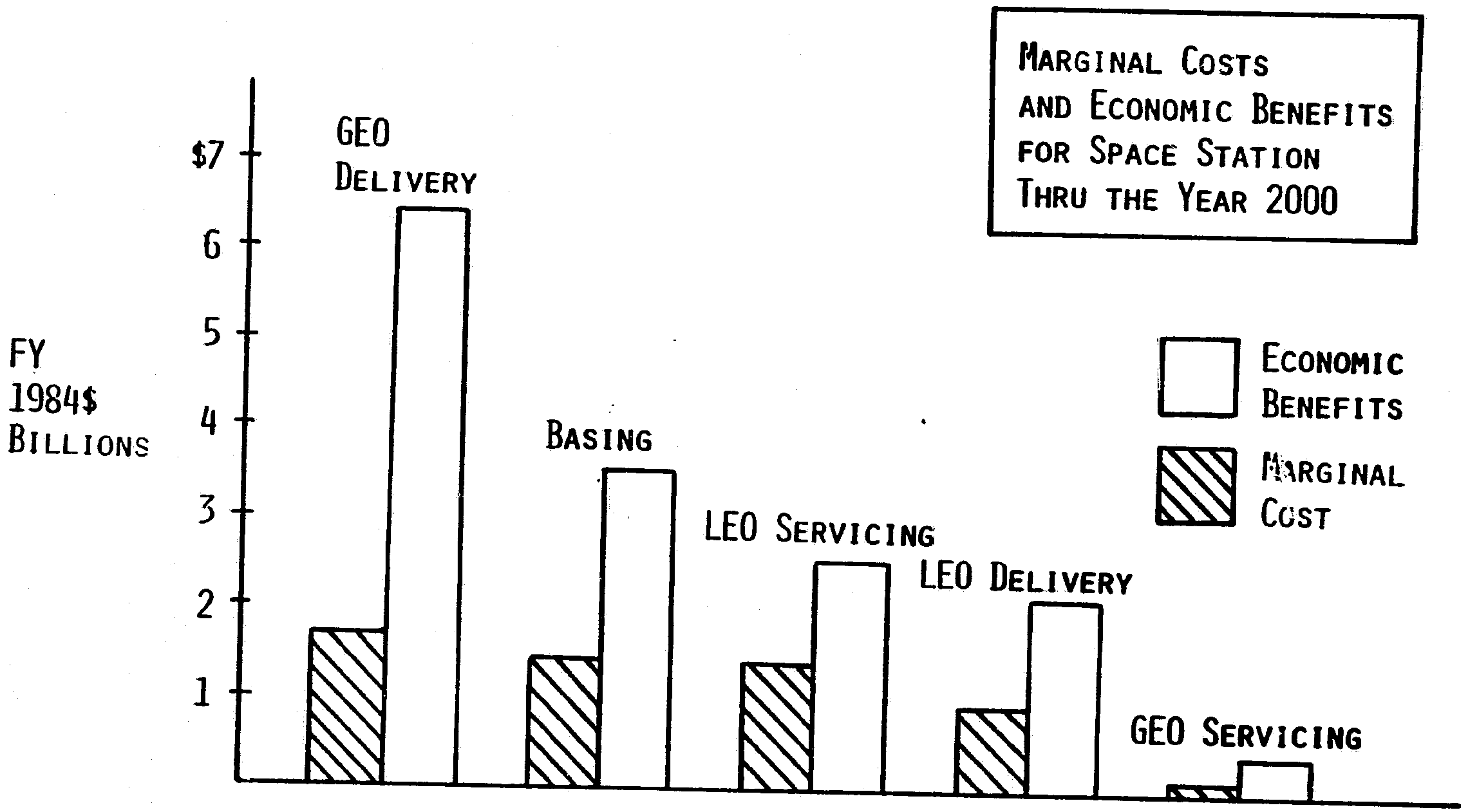

Figure 4.1-2 Marginal Costs and Economic Benefits By Capability Increment

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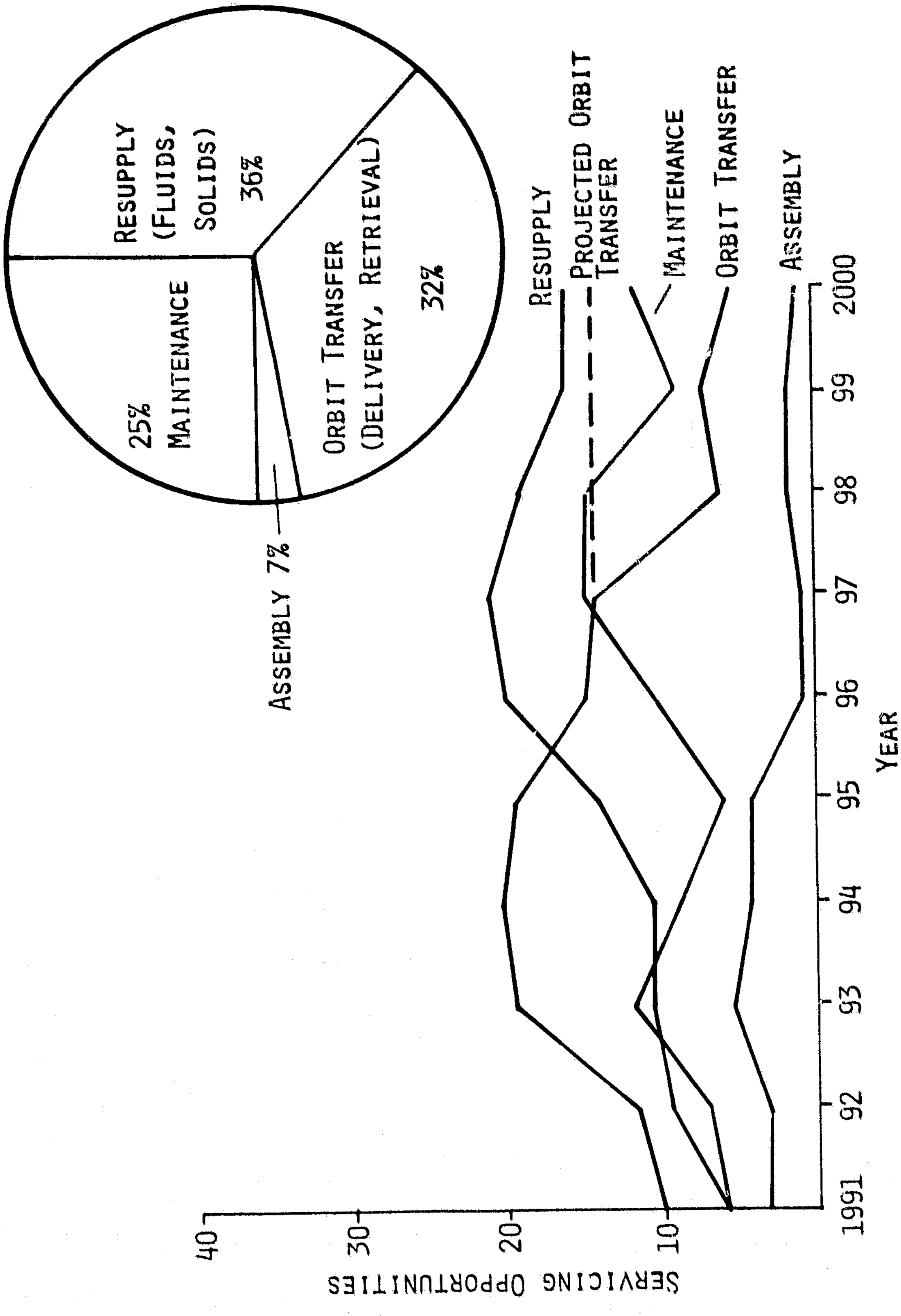


Figure 4.1-3 Timed Phased Servicing Tasks

Table 4.1-1 Critical Items

Critical Items	High Payoff	Technical Risk	Development Span	Critical Path
OTV - Space Based, Aerobraked	X	X	X	X
Rendezvous and Docking System	X	X	X	
TMS - Space Based	X	X		
Spacecraft Standardization	X		X	
Orbital Fluid Transfer	X	X		

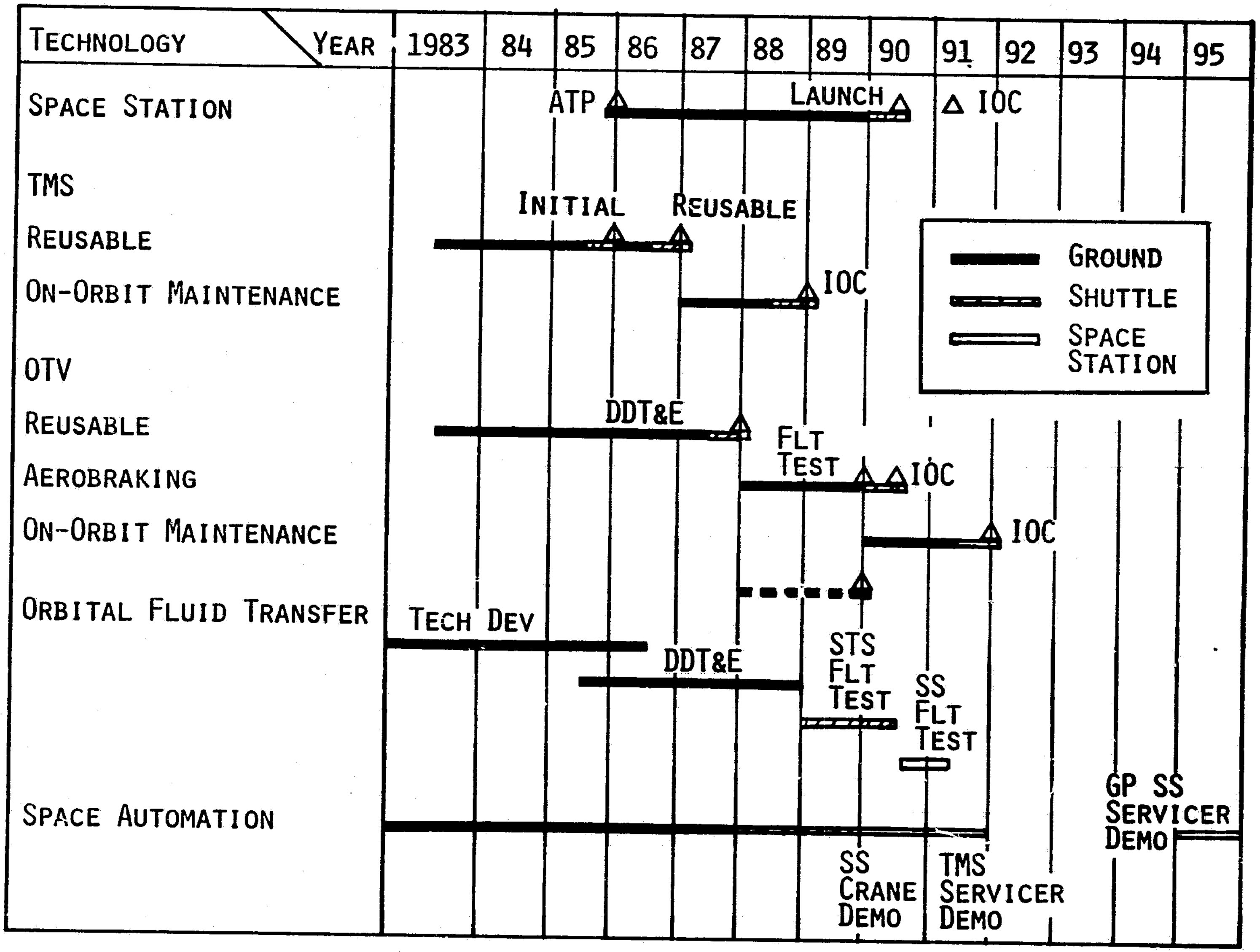


Figure 4.1-4 Critical Precursor Technology Schedules

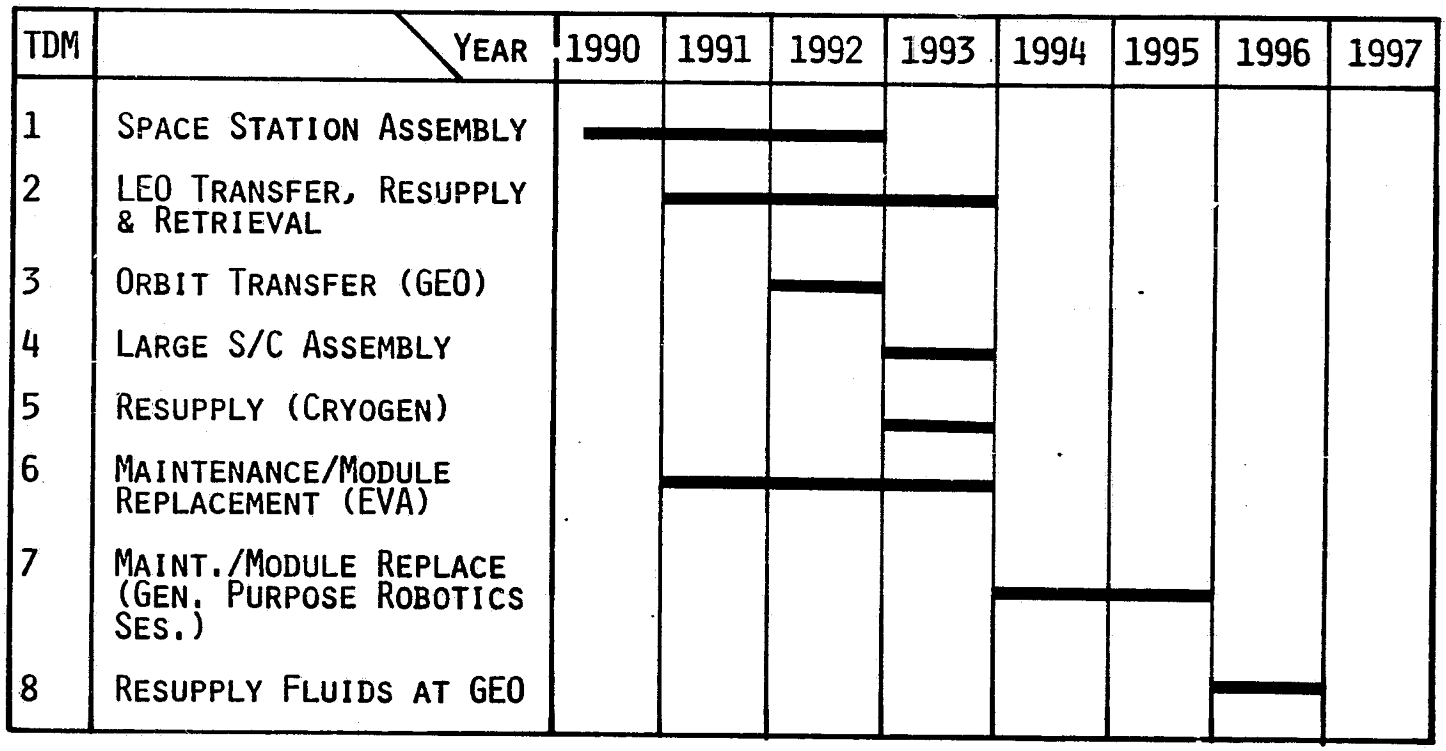


Figure 4.1-5 Technology Development Missions Schedule

By definition the space station assembly TDM must be accomplished before the other TDMs. If the benefit to cost ratio were the only selection criteria, the GEO orbital transfer TDM would be next. However, due to the development time for a space based OTV on the space station we delayed the orbital transfer TDM until 1992. We scheduled TDM 2 early because of its compatibility with the space station evolution and its high economic payoff potential. The other TDMs were sequenced based on those that give the highest benefit to cost ratio.

4.2 COST ANALYSIS

We chose to select real repair missions for our TDMs because we believe this approach results in a more cost effective mission. Table 4.2-1 delineates the estimated costs associated with performing TDM 7, which is maintenance/module replacement and fluid resupply of the Advanced X-Ray Astrophysics Facility (AXAF) using a general purpose robotic servicer at the space station. The costs are allocated into the following three cost categories; (1) those funded by the AXAF mission, (2) those funded by the space station system, and (3) those unique to TDM 7. Note that most of TDM 7 total costs are space station common costs (56%) which include a general purpose robotic servicer, payload carriage, carousel mechanism, and module service tool. The AXAF mission unique costs represent 33% of TDM 7 total cost and includes operations planning and support, AXAF cradle, replacement module storage, checkout support equipment, and umbilicals. The TDM 7 unique costs are only about 11% of the total TDM 7 costs and include research and technology, operations planning and support, experiment hardware, and support equipment. If TDM 7 was performed using a "dummy" satellite many of the AXAF mission unique costs would become TDM 7 unique costs.

A significant portion of TDM 7 costs is for operations planning and analysis that must be completed for each repair mission. Prior to conducting any satellite service mission the following plans and data packages will need to be prepared: (1) mission operations plan, (2) payload data package, (3) flight plans, (4) flight operations support plan, (5) space station command and data package (6) payload operations control center activities plan, (7) space station crew operations plan, (8) training plan, (9) launch site support plan, (10) payload interface verification summary, (11) EVA activities plan and (12) a safety plan. These plans and data packages were itemized as part of our cost analysis task to estimate the mission planning effort required for the TDMs. The TDM 7 plans and the costs for developing them were estimated by analogy to our on-going Solar Max Repair Mission planning.

TDM 7 unique costs assume that precursor general robotics development has been completed. The TDM 7 unique costs included are supporting research and technology, advanced technology requirements, operations planning and support, technology development experiment hardware, flight support equipment, and ground support equipment. Table 4.2-2 presents the unique funding requirements in plot and table form for both total funding and fiscal year funding of TDM 7. It is estimated that peak funding for TDM 7 unique will occur in FY 1992 at $2.7 million for the year.

Table 4.2-1 TDM 7 Associated Costs

TDM Costs

AXAF Mission Unique Costs $22M

- Ops Planning & Support
- AXAF Cradle
- Replacement Module Storage
- Checkout Support Equipment
- Umbilicals

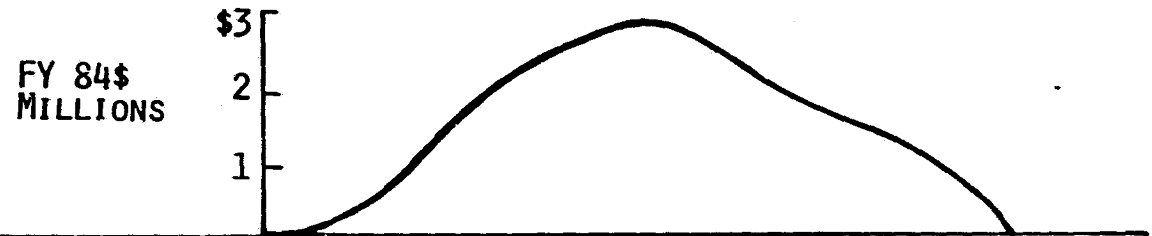
Space Station Common Costs $38M

- General Purpose Robotic Servicer
- Payload Carriage
- Carousel Mechanism
- Module Service Tool

TDM 7 Unique Costs $7.4M

- Research & Technology
- Operations Planning & Support
- Experiment Hardware
- Support Equipment

Table 4.2-2 TDM 7 Unique Funding Requirements



FY / COST ELEMENT	1990	1991	1992	1993	1994	TOTAL
SRT & ATR	$0.2	0.3	0.2	--	--	$0.7
OPERATIONS PLANNING/SPT.	--	0.4	0.5	1.0	0.8	2.7
EXPERIMENT HARDWARE	--	1.0	1.3	0.3	--	2.6
FLIGHT SPT. EQUIP.	--	0.2	0.4	0.2	--	0.8
GROUND SPT. EQUIP.	--	0.1	0.3	0.2	--	0.6
TOTAL	$0.2	2.0	2.7	1.7	0.8	$7.4

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In conclusion, our programmatic analysis indicates that TDMs should be prioritized using the benefit to cost ratio of each TDM to determine the most economically beneficial, time-phased TDM sequence. The time-phasing of selected TDMs will help to identify the critical items that could have an impact on satellite servicing done at or by a space station system. Solutions to the critical items will result from development of critical precursor technologies which will determine the critical path.

APPENDIX A ACRONYMS AND ABREVIATIONS

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A	Angstrom
AC&S	Attitude Control and Stabilization
ACC	Aft Cargo Carrier
ACS	Attitude Control Subsystem
ACTS	Advanced Communications Satellite Corporation
AFB	Air Force Base
AHUT	Animal Holder and Unit Tester
AIAA	American Institute of Aeronautics and Astronautics
AIE	Advanced Interplanetary Explorer
AL	Airlock
AMIMS	Advanced Meteorological Infrared & Microwave Soander
AMPTE	Active Magnetosphere Particle Tracer Experiment
AO	Announcement Opportunity
AP	Action Potential
ARC	Arnold Research Center
ASE	Airborne Support Equipment
ASO	Advanced Solar Observatory
ASTO	Advanced Solar Terrestrial Observatory
ATP	Authority to Proceed
AXAF	Advanced X-Ray Astrophysics Facility
B	Billion
BCK	Blood Collection Kit
BIT	Built-In Test
BITE	Built-In-Test-Equipment
BIU	Bus Interface Unit

APPENDIX A ACRONYMS AND ABREVIATIONS

BOL	Beginning of Life
BTS	Biotelemetry System
C	Core
c	Centigrade
Ca	Calcium
CB	Cargo Bay
C&DH	Command and Data Handling Subsystem
CDP	Coronal Diagnostic Package
CDR	Critical Design Review
CELSS	Controlled Environment Life Support System
CER	Cost Estimating Relationship
CF	Construction Facility
CG	Center of Gravity
Cl	Chloride
CLIR	Cryogenics Limb Scanning Interferometer & Radiometer
CM	Command Module
CMD	Command
CMG	Control Moment Gryo
CMM	Composite Mission Model
CO_2	Carbon Dioxide
COBE	Cosmic Background Explorer
COMPMM	Composite Mission Model
COMSAT	Communications Satellite Corporation
COSMIC	Coherent Optical System Modular Imaging Collector
CR	Comet Rendezvous

APPENDIX A ACRONYMS AND ABREVIATIONS

CRM	Chemical Release Module
CRMF	Chemical Release Module Facility
CRO	Cosmic Ray Observatory
CRT	Cathode-Ray Tube
CSR	Comet Sample Return
CZCS	Coastal Zone Color Scanner
DBS	Direct Broadcast Satellite
DBV	Derived Boost Vehicle
DDT&E	Design Development, Test and Evaluation
DEMS	Dynamic Environment Monitoring System
DMPS	Data Management and Processing System
DOD	Department of Defense
DRM	Design Reference Mission
DSN	Deep Space Network
EAAR	Earth Approaching Asteroid Rendezvous
ECG	Electrocardiograph
ECLS	Environmental Control Pipe Support
ECLSS	Environmental Control/Life Support Systems
ECS	Environmental Control System
EEG	Electroencephalogram
e.g.	Example
EKG	Electromyogram
ELS	Eastern Launch Site
EMC	Electromagnetic Compatibility

APPENDIX A ACRONYMS AND ABREVIATIONS

EMG	Electromyogram
EMI	Electromagnetic Interference
EMU	Extravehicular Mobility Unit
ENG	Electonystagnogram
EOL	End of Life
EOS	Electrophoresis Operations In Space
EOTV	Expendable Orbital Transfer Vehicle
EPS	Electrical Power
EPDS	Electrical Power and Distribution System
ERB	Earth Radiation Budget
ET	External Tank
ETCLS	Environmental and Thermal Control and Life Support
EUVE	Extreme Ultraviolet Explorer
EVA	Extra-Vehicular Activity
Exper	Experimeter
Expmt	Experiment
fps	Feet per Second
FCC	Federal Communications Commission
FDMA	Frequency-Division Multiple Access
FF	Free Flyer
FILE	Feature Identification and Location Experiment
FLOPS	Floating Point Operations Per Second
FOC	Full Operating Capability
FOCC	Flight Operations Control Center
FOT	Faint Object Telescope

APPENDIX A ACRONYMS AND ABREVIATIONS

FSF	First Static Firing
FUSE	Far Ultraviolet Spectroscopy Explorer
FY	Fiscal Year
g	Gravity
GG	Gravity Gradient
G_Z	Vertical Gravity Acceleration Component
GaAs	Galium Arsemide
GEO	Geosynchronous Earth Orbit
GEOSTO	Geosynchronous Solar Terrestrial Observatory
GFP	Government-Furnished Property
GG	Gravity Gradiometer
GHZ	Gigadertz
GMC	Ground Mission Control
GND	Ground
GPS	Global Positioning System
GPWS	General Purpose Work Station
GRIST	Grazing Incidence Solar Telescope
GRO	Gamma Ray Observatory
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
GSS	Ground Support System
GSSI	Geosynchronous Satellite Sensor Intercalibration
GTE	Gamma Ray Timing Explorer

APPENDIX A ACRONYMS AND ABREVIATIONS

H	Hangar
H_2O	Water
H/W	Hardware
HM	Habitation Module
HMF	Health Maintenance Facility
HNE	Heavy Nuclei Explorer
HOL	Higher Order Language
I&C	Installation and Checkout
I/F	Interface
ID	Identification
INTELSAT	International Telecommunications Satellite Organization
IOC	Initial Operating Capability
IPS	Instrument Pointing System
IR	Infrared
IRAS	Infrared Astronomy Satellite
IRD	Instrument Research Division
IS	Imaging Spectrometer
ISP	Initial Specific Impulse
ISPM	International Solar Polar Mission
ISTO	Initial Solar Terrestrial Observatory
IUE	International Ultra Violet Explorer
IVA	Intravehicular Activity
JEA	Joint Endeavor Agreement
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center

APPENDIX A ACRONYMS AND ABREVIATIONS

K	Potassium
Kbps	Kilobits Per Second
KG, kg	Kilogram
KSC	Kennedy Space Center
KW, kw	Kilowatt
lbm	Pounds
LAMAR	Large Area Modular Array Reflectors
LAMMR	Large Antenna Multifrequency Microwave Radiometer
LaRC	Langley Research Center
LBNP	Lower Body Negative Pressure
LBNPD	Lower Body Negative Pressure Device
LDR	Large Deployable Reflector
LEO	Low Earth Orbit
LeRC	Lewis Research Center
LIDAR	Light Detection and Ranging
LiOH	Lithium Hydroxide
LM	Logistics Module
LMMI	Large Mass Measurement Instrument
LSEPS	Large Spacecraft Effects on Proximate Space
LSLE	Life Sciences Laboratory Equipment
LSLF	Life Sciences Laboratory Facility
LSM	Life Support Module
LSRF	Life Sciences Research Facility
LSRM	Life Sciences Research Module
LSS	Life Support Systems

APPENDIX A ACRONYMS AND ABREVIATIONS

LRU	Line Replaceable Unit
LWA	Long Wavelength Antenna
mV	Millivolt
M	Million
MAM	Main Belt Asteroid Multirendezvous
Mbps	Megabits Per Second
MD	Medical Doctor
MDAC	McDonnell Douglas Astronautics Company
MeV	Million Electron Volts
MGCM	Mars Geochemistry/Climatology Mapper
MMC	Martin Marietta Corporation
MML	Martin Marietta Laboratories
MMS	Multimission Modular Spacecraft
MMU	Manned Maneuvering Unit
MOHM	Megaohms
MOTV	Manned Orbital Transfer Vehicle
MP	Materials Processing
MPN	Mars Probe Network
MPS	Materials Processing in Space
MR	Microwave Radiometer
MRICD	Medical Research Institute for Chemical Defense
MRWS	Mobile Remote Work Station
M-SAT	Mobile Satellite
MSFC	Marshall Space Flight Center
MWPC	Multi-Wire Proportional Counter
MWS	Microwave Sounder

APPENDIX A ACRONYMS AND ABREVIATIONS

N/A	Not Applicable
NASA	National Aeronautics and Space Administration
NiH_2	Nichel Hydrogen
NM	Nautical Miles
NMR	Nuclear Magnetic Resonance
ODSRS	Orbiting Deep Space Relay Station
OIST	Orbiting Infrared Submillimeter Telescope
OMP	Ocean Microwave Package
OMS	Orbital Maneuvering Systems
O_2	Oxygen
O_2/N_2	Oxygen/Nitrogen
OPEN	Origin of Plasma in the Earth Neighborhood
OSA	Optical Society of America
OTV	Orbital Transfer Vehicle
OVLBI	Orbital Very Long Baseline Interferometer
P	Phosphorous
PDR	Preliminary Design Review
PET	Position Emission Tomography
PhD	Doctorate of Philosophy
PH	Level of Acidity
PI	Principal Investigator
PIDA	Payload Installation and Deployment Aid
P/L	Payload
PLSS	Portable Life Support Systems/Personal Life Support System

APPENDIX A ACRONYMS AND ABREVIATIONS

PMD	Propellant Management Device
PMS	Physiological Monitoring System
P/OF	Pinhole/Occulter Facility
PS	Payload Specialist
psi	Pounds per Square Inch
psia	Pounds per Square Inch Absolute
PTE	Plasma Turbulence Explorer
QD	Quick Disconnect
R&D	Research and Development
R&T	Research and Technology
RAHF	Research Animal Holding Facility
RBC	Red Blood Cell
RCA	Radio Corporation of America
REM	Roentgen Equivalent, Mass
RF	Radio Frequency
RFP	Request for Proposal
RMS	Remote Manipulator System
ROM	Rough Order of Magnitude
ROSS	Remote Orbital Servicing System
ROTV	Reusable Orbital Transfer Vehicle
SAR	Synthetic Aperture Radar
SARSAT	Search and Rescue Satellite - Aided Tracking
SAT	Satellite

APPENDIX A ACRONYMS AND ABREVIATIONS

S/C	Spacecraft
SCADM	Solar Cycle and Dynamics Mission
SCDM	Solar Coronal Diagnostic Mission
SCE	Solar Corona Explorer
SDCV	Shuttle Derived Cargo Vehicle
SDV	Shuttle Derived Vehicle
SERV	Servicing
SEXTF	Solar EUV/XUV Telescope Facility
SHEF	Solar High Energy Facility
SIDM	Solar Interior Dynamics Mission
SIDF	Solar Interior Dynamics Facility
SIRTF	Shuttle Infrared Telescope Facility
SIS	Solar Interplanetary Satellite
SL	Spacelab
SLFRF	Solar Low Frequency Radio Facility
SMMI	Small Mass Measurement Instrument
SOMS	Shuttle Orbiter Medical Systems
SO/P	Saturn Orbiter/Probe
SOT	Solar Optical Telescope
SP	Scientific Payload
SPELS	Space Plasma Effects on Large Spacecraft
SPIE	Society Photo-Optics Instrument Engineers
SRB	Solid Rocket Booster
SRR	Systems Requirements Review
SS	Space Station
SSCAG	Space System Cost Analysis Group

APPENDIX A ACRONYMS AND ABREVIATIONS

SSEC	Solar Systems Exploration Committee
SSF	Solar Shuttle Facility
SSL	Space Sciences Laboratory
SSMC	Space Station Mission Control
SSMM	Space Station Mission Model
SSR	Solar Spectrometer/Radiometer
SSRMS	Space Station Remote Manipulator System
SSXTF	Solar Soft X-Ray Telescope Facility
ST	Space Telescope
STDN	Space Tracking and Data Network
STO	Solar Terrestrial Observatory
STS	Space Transportation System
SVI	Stereo Visual Image
TAT	Thinned Aperture Telescope
TBD	To Be Determined
TBR	To Be Required
TBS	To Be Supplied
TCS	Thermal Control Subsystem
TDAS	Tracking and Data Acquisition System
TDM	Technology Development Mission
TDMA	Time-Division Multiple Access
TDRS	Tracking and Data Relay Satellite
TDRSS	TDRS System
TEM	Transmission Electron Microscopy
THM	Tethered Magnetometer

APPENDIX A ACRONYMS AND ABREVIATIONS

TIMI	Thermal Infrared Multispectral Imager
TM	Technical Memorandum
TMS	Teleoperator Maneuvering System
TOPEX	Ocean Topography Experiment
TP	Thermal Panels
TPS	Thermal Protection System
TSS	Time Sharing System
TV	Television
um	Micrometer = micron
usec	Microsecond
uvolt	Microvolt
UARS	Upper Atmosphere Research Satellite
UHF	Ultra High Frequency
Ult	Ultimate
UMS	Urine Monitoring System
US	Upper Stage
USRA	University Space Research Association
UV	Ultraviolet
V	Velocity
VAP	Venus Atmospheric Probe
VAFB	Vandenberg Air Force Base
Vdc	Volts Direct Current
VFR	Vestibular Function Research
VHEO	Very High Earth Orbit

APPENDIX A ACRONYMS AND ABREVIATIONS

VHSIC	Very High Speed Integrated Circuit
VLR	Very Large Radar
VLST	Very Large Space Telescope
VRF	Vestibular Research Facility
VRM	Venus Radar Mapper
WARC	World Administration Radio Conference
WBS	Work Breakdown Structure
WLS	Western Launch Site
WRU	Work Restraint Unit
XGP	Experimental Geostationary Platform
XRO	X-Ray Observatory
XTE	X-Ray Timing Explorer
Zero g	Zero Gravity
β angle	Angle Between Orbit Plane and Solar Vector
α_s	Coating Solar Absorptance
ε	Coating Emmitance
ω	Watts

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